AD-A102 892    ARMY ENGINEER WATERWAYS EXPERIMENT STATION  VICKSBURG MS    F/G 13/2
EFFECTS OF DEPTH ON DREDGING FREQUENCY. REPORT 2, METHODS OF ES--ETC(U)
JUL 81   M J TRAWLE
UNCLASSIFIED   WES-TR-H-78-5                                    NL

1 OF 2
AD A
102892

LEVEL III

AO 56042



TECHNICAL REPORT H-78-5

# EFFECTS OF DEPTH ON DREDGING FREQUENCY

Report 2

## METHODS OF ESTUARINE SHOALING ANALYSIS

by

Michael J. Trawle

Hydraulics Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180



July 1981

Report 2 of a Series

Approved For Public Release; Distribution Unlimited

Prepared for Office, Chief of Engineers, U. S. Army
Washington, D. C. 20314

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

# REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

| | |
|---|---|
| 1. REPORT NUMBER: Technical Report H-78-5 | 2. GOVT ACCESSION NO.: AD-A102892 |
| 3. RECIPIENT'S CATALOG NUMBER | |
| 4. TITLE (and Subtitle): EFFECTS OF DEPTH ON DREDGING FREQUENCY. Report 2. METHODS OF ESTUARINE SHOALING ANALYSIS | 5. TYPE OF REPORT & PERIOD COVERED: Report 2 of a series |
| | 6. PERFORMING ORG. REPORT NUMBER |
| 7. AUTHOR(s): Michael J. Trawle | 8. CONTRACT OR GRANT NUMBER(s) |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS: U. S. Army Engineer Waterways Experiment Station, Hydraulics Laboratory, P. O. Box 631, Vicksburg, Miss. 39180 | 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS |
| 11. CONTROLLING OFFICE NAME AND ADDRESS: Office, Chief of Engineers, U. S. Army, Washington, D. C. 20314 | 12. REPORT DATE: July 1981 |
| | 13. NUMBER OF PAGES: 132 |
| 14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) | 15. SECURITY CLASS. (of this report): Unclassified |
| | 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE |

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Available from National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22151.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Channel improvement
Dredging
Harbors
Maintenance dredging
Shoaling

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Whenever deepening of a dredged channel is under investigation, a prediction must be made as to the effect of the deepening on the existing dredging requirements. If the deepening is related to advance maintenance dredging rather than to an increase in authorized depth, the prediction becomes even more difficult because the project is allowed to shoal over a wide range of depth. Currently a variety of arbitrary, rule-of-thumb procedures are used for predicting the effect of increased depth on dredging requirements.

(Continued)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

038100

20. ABSTRACT (Continued).

The overall objective of this investigation was to evaluate the effectiveness of advance maintenance dredging in reducing dredging frequency and/or costs in the maintenance of coastal channels and harbors and to establish necessary guidelines for governing the practice. This report, the second of a series, presents an empirical method of shoaling analysis based on historical dredging and shoaling records that results in reliable predictions of future shoaling for deepened channel conditions resulting from either an increase in authorized channel depth or advance maintenance. The method presented was designed to be general enough so that it can be applied to most navigation projects without difficulty. The procedure was described step by step using an example (fictitious) project. To demonstrate how the method would be applied to real navigation projects and to point out problems that occur when evaluating real projects, selected Galveston Bay, Texas, navigation projects were evaluated and the results discussed.

PREFACE

The study reported herein was conducted by personnel of the Hydraulics Laboratory, U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi, under the Improvement of Operations and Maintenance Program, Office, Chief of Engineers, U. S. Army.

The study was conducted during the period 1 July 1976 to 31 March 1978 under the direction of Messrs. H. B. Simmons, Chief of the Hydraulics Laboratory; F. A. Herrmann, Jr., Assistant Chief of the Hydraulics Laboratory; R. A. Sager, Chief of the Estuaries Division; R. A. Boland, Chief of the Interior Channel Branch; and W. H. McAnally, Technical Advisor for Estuaries Research Projects, Estuaries Division. This report was prepared by Mr. M. J. Trawle, Project Engineer, with the assistance of Messrs. Boland and McAnally.

Commanders and Directors of WES during the investigation and the preparation and publication of this report were COL John L. Cannon, CE, and COL Nelson P. Conover, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

| Multiply | By | To Obtain |
|---|---|---|
| feet | 0.3048 | metres |
| cubic yards | 0.7645549 | cubic metres |
| miles (U. S. statute) | 1.609344 | kilometres |

EFFECTS OF DEPTH ON DREDGING FREQUENCY

METHODS OF SHOALING ESTUARINE ANALYSIS

# PART I: INTRODUCTION

## Objective

1. The overall objective of this investigation is to evaluate the effectiveness of advance maintenance dredging in reducing dredging frequency and costs in estuarine channel and harbor maintenance and to establish guidelines necessary for governing this practice.

2. The objective of this report is to present an empirical method of shoaling analysis based on historical dredging and shoaling records that results in reliable predictions of future shoaling for deepened channel conditions. Deepened conditions can result either from an increase in the authorized channel depth or from advance maintenance dredging.

## Background

3. A typical dredged channel with no provision for advance maintenance dredging is illustrated in Figure 1. Basic specifications for the dredged dimensions are authorized depth, authorized bottom width, and authorized side slopes which describe the authorized channel prism. Where advance maintenance dredging is not utilized, the authorized channel is the same as the required channel prism. The inclusion of allowable dredging tolerances for the bottom and side slopes of the channel to compensate for dredging inaccuracies provides for adjusted channel dimensions which define the allowable pay prism of the channel.

4. Allowable dredging tolerance should not be confused with advance maintenance dredging (Figure 2). Allowable dredging tolerance, usually 1 to 3 ft,* is simply a margin of error that allows the contractor to be

---

* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 3.

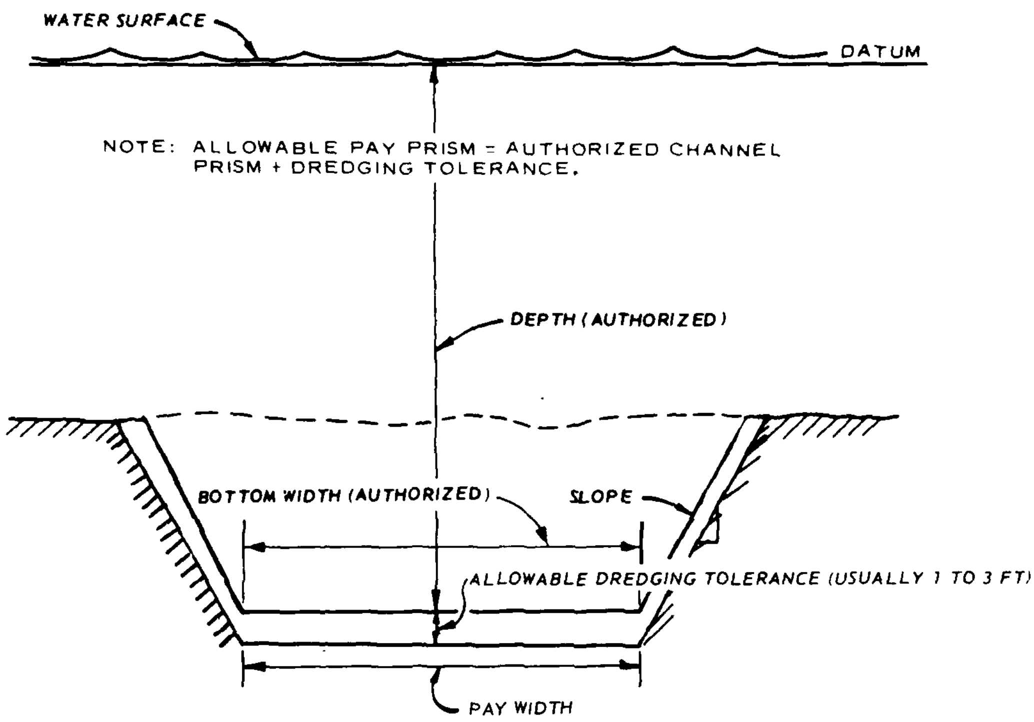



Figure 1. Typical dredged channel cross section

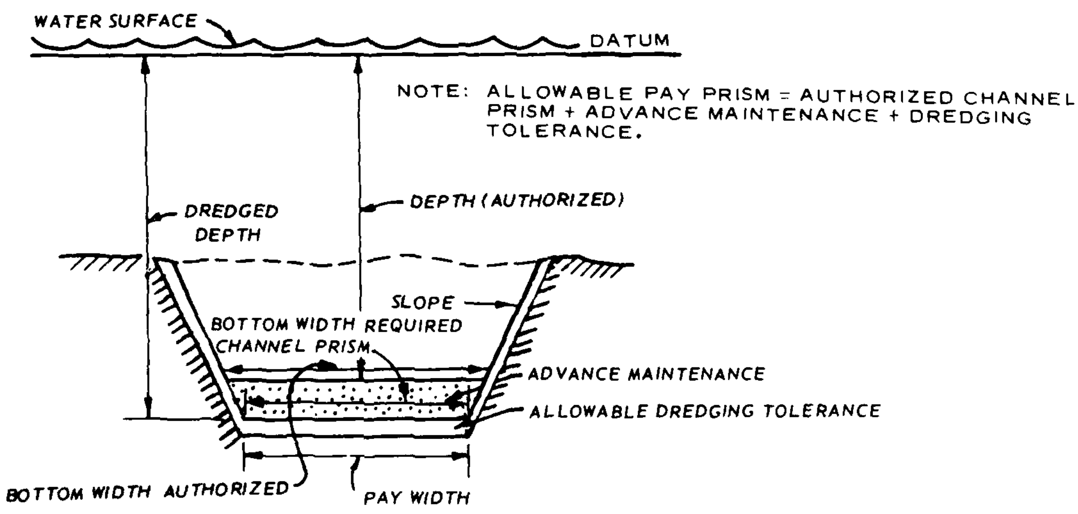



Figure 2. Dredged channel cross section with advance maintenance included

paid for material dredged within a specified depth (usually 1 to 3 ft) below the authorized depth. Allowable dredging tolerance is necessary to allow for dredging inaccuracies. Factors that contribute to the need for a tolerance for industry and for Corps dredges include wave action, tidal forecast variances, and equipment conditions and controls.

5. Whenever deepening of a dredged channel is being investigated, a prediction must be made as to the effect of the deepening on the existing dredging requiements. If the deepening is related to advance maintenance dredging rather than to an increase in the authorized depth, the prediction becomes even more difficult because the project is allowed to shoal over a wide range of depth. As a result of the environmental regulations created within the last decade, dredging has become a much more expensive operation than in the past, and costs will be felt even more heavily in the future. For this reason, predictions of shoaling for deepened conditions, whether advance maintenance dredging or increase in authorized depth, should be reliable. Currently a variety of procedures are followed by Corps districts for predicting the effect of depth on dredging requirements. Four of the most used procedures in the past are presented in the following subparagraphs:

a. Increase in cross-sectional area. The basic premise in this procedure is that for any dredged navigation channel, the percent increase in the shoaling rate caused by deepening is proportional to the percent increase in cross-sectional area of the channel below natural depth (Figure 3) or, presented in equational form,

$$S_d = S\left(\frac{A_d}{A}\right)$$

where

$S$ = existing channel shoaling rate

$S_d$ = deepened channel shoaling rate

$A$ = existing channel cross-sectional area

$A_d$ = deepened channel cross-sectional area

b. Increase in wetted perimeter. The basic premise in this procedure is that for any dredged navigation channel, the percent increase in the shoaling rate caused by deepening is proportional to the percent increase in the wetted perimeter of the channel below natural depth (Figure 3) or, presented in equational form,

$$S_d = S\frac{x_d + y_d + z_d}{x + y + z}$$

where

- $S$ = existing channel shoaling rate
- $S_d$ = deepened channel shoaling rate
- $x$ = length of existing channel side slope (left)
- $y$ = length of existing channel bottom
- $z$ = length of existing channel side slope (right)
- $x_d$ = length of deepened channel side slope (left)
- $y_d$ = length of deepened channel bottom
- $z_d$ = length of deepened channel side slope (right)

c. Experience in nearby areas. When navigation channels in nearby areas have already been deepened to the depth being considered for the channel under investigation, results of the deepening in the nearby channel may be used to predict the future dredging requirements for the channel in question. It should be noted that this procedure has considerable potential for distorted results when comparison areas have included engineered modifications such as diking, bank protection, variable flows from dam releases, or any other engineering modifications which would create significant dissimilarities.

d. Limited historical dredging or shoaling data. Often the prediction of shoaling for a deepened channel is made on the basis of limited historical dredging or shoaling data. For example, based on hydrographic surveys of a navigation channel, suppose it's determined that for a period between dredging (say 3 yr) for the existing channel depth, the shoaling rate was X cu yd per year. For a period between dredging for the previous channel depth (say 4 ft less than that existing), the shoaling rate was Y cu yd per year. The percent increase in shoaling from the previous to existing depth is simply

$$\text{Percent increase in shoaling} = \frac{100(X - Y)}{Y}$$

The rate of increase can then be extrapolated to the greater depths being considered. If a few more data points are available, a predictive equation can even be generated that allows for other than a linear extrapolation.

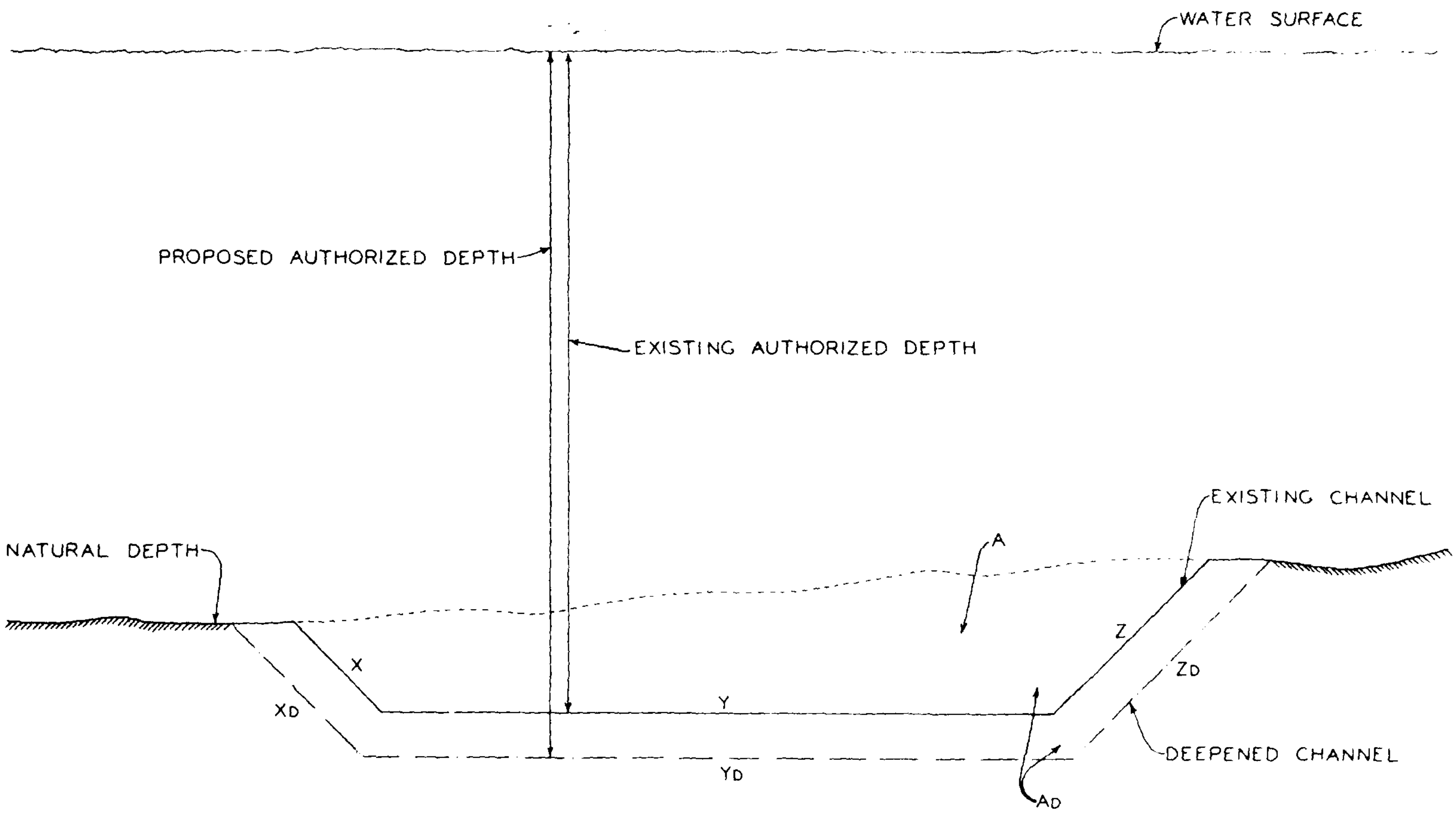



Figure 3. Channel cross section for existing and enlarged dimensions

6. Of the four procedures above, the first two--increase in cross-sectional area and increase in wetted perimeter--are based on the assumption that all navigation channel shoaling increases with depth can be related, at least approximately, to some function of channel geometry such as cross-sectional area or wetted perimeter. The problem with this approach is that the assumption is often not valid. Each navigation channel should be treated as unique, since shoaling depends on a multitude of factors, including such factors as sources and types of shoaling material, wind and wave action, ship traffic, past dredging practices, floods, droughts, storms, and changes in density currents, as well as geometry. To assume that shoaling can be predicted on the basis of channel geometry alone is a gross oversimplification and should not be considered reliable. This procedure should not be utilized by Corps personnel.

7. The third method, presented in subparagraph 5c, can be a valid method of prediction if the channel in the nearby area is indeed similar to the channel being evaluated. However, one cannot assume that a channel will behave the same as a nearby channel based on proximity alone. Again this is an oversimplification resulting in a prediction that should not be considered reliable.

8. The fourth method of shoaling analysis, presented in subparagraph 5d, differs from the others presented in that the prediction is based on historical dredging or shoaling data. The problem with the approach usually lies in the fact that the amount of data used in the evaluation is insufficient to determine representative shoaling rates. The nature of shoaling phenomena requires that long periods of time be evaluated because the variance in short-term shoaling for most projects is tremendous. In many cases, a few short time periods with one set of channel dimensions are compared with a few short time periods at another set of dimensions; and a prediction for deepened condition is made based on the limited historical data evaluated. The approach can result in (a) shoaling rates not representative of the corresponding channel dimensions and (b) a poor predictive model. As a general rule, the more historical dredging and shoaling data used in the evaluation of a project,

the more likely a predictive model that extrapolates the data will be valid.

## Approach

9. The method of shoaling analysis presented will be first described step by step in PART II of this report, using an example project. The example project is fictitious and was created to be typical of many estuarine dredged navigation projects maintained by the Corps of Engineers. In PART III of this report the method will be applied to several real dredged navigation projects maintained by the Corps.

10. For any dredged navigation project, shoaling rates are considered to vary in both time and space. For example, the shoaling rate at one location and depth is not constant over time. The shoaling rates at the same location and time but at different depths are not necessarily the same. The shoaling rates at the same depth and time but at different locations within the project are not the same. The variation of shoaling with time may be cyclical in nature as in the case of seasonal changes; there may be a long-term, man-induced, or natural change which gradually affects the shoaling rates within the project; or there may be abrupt changes caused by shocks to the system such as storms or man-made modifications in nearby areas such as dams, locks, flow diversions, and so on. All of these factors should be considered in the analysis of shoaling for any dredged navigation project.

## Assumptions

11. Ideally, a predictive scheme for deepening and subsequent shoaling analysis would include all factors that affect the shoaling rates within a dredged navigation channel, a goal which is generally not achievable. In the method of shoaling analysis presented in PARTS II and III of this report, the following simplifying assumptions were made:

a. The variation in shoaling rates within a project can be discretized to form a reasonable number of sections. For example, a 6000-ft-long channel could be divided into six 1000-ft sections and an average shoaling rate for each section for a given depth used in subsequent computations, as long as the shoaling within each section was relatively evenly distributed. This discretization procedure could tie in quite nicely with the frequently used dredging clause which indicates that the project is divided into "acceptance sections" with lengths ranging from 1000 to 3000 ft or so.

_b_. The variation in shoaling rate with depth for a given location can be discretized to form a reasonable number of depth intervals. For example, if shoaling was being considered at depths from 40 to 50 ft, the variation in shoaling with depth for a given location could be discretized to form 1- to 4-ft intervals (40 to 44 ft, 44 to 46 ft, 46 to 49 ft, and 49 to 50 ft) for computational purposes.

_c_. Short-term variation in shoaling, such as seasonal variation, is not considered, since most shoaling intervals (periods between dredging activity) to be investigated in estuarine navigation projects are at least 1 yr in length. However, if the shoaling is highly seasonal and sufficient data are available to develop shoaling rates with respect to depth for each appropriate period (for example, April through October and November through March), the method in this report could be applied to each period and results coupled.

_d_. Channel depth changes within the range considered do not significantly affect the distribution of shoaling material within the project. The validity of this assumption for a particular project can be addressed by inspection of the shoaling distribution patterns during previous project depth increases.

## PART II: DISCUSSION OF METHODS

12. In order to demonstrate the methods to be used in shoaling analyses, an example estuarine navigation project has been created as an example and will be evaluated. The project is fictitious and not based on any specific real project. The project was initiated in FY 1930 with new work dredging of 1.52 million cu yd in FY 1930, 1.57 million cu yd in FY 1931, and 0.47 million cu yd in FY 1932, resulting in a 10-mile-long channel of 30-ft depth* and 300-ft width. Maintenance dredging was performed periodically between FY 1932 and FY 1943, ranging in volume from none to 1.42 million cu yd in FY 1943. During FY 1943, new work dredging of 1.35 million cu yd was conducted to deepen the project, resulting in a 10-mile-long channel of 32-ft depth and 300-ft width. Periodic maintenance dredging was performed between FY 1944 and FY 1959, ranging in volume from none to 1.40 million cu yd in FY 1959. During FY 1960 and FY 1961, new work dredging of 3.03 and 1.24 million cu yd, respectively, was conducted to deepen and widen the project, resulting in a 10-mile-long channel of 34-ft depth and 400-ft width. Periodic maintenance dredging was performed between FY 1960 and FY 1966, ranging from none to 2.03 million cu yd in FY 1963. During FY 1967, new work dredging of 1.89 million cu yd was conducted to deepen the project, resulting in a 10-mile-long channel of 36-ft depth and 400-ft width. Periodic maintenance dredging was performed from FY 1967 to FY 1975, ranging from none to 2.81 million cu yd in FY 1975. The dredging history for the project, similar to information that can be extracted from the Corps of Engineers Annual Reports and including both new work and maintenance dredging volumes, is presented in Table 1. It is assumed that advantage is taken of the 2-ft dredging tolerance allowance each time the channel is dredged (new work or maintenance). Thus, the channel depth immediately after each dredging operation would be 1 or 2 ft greater than the authorized project depth.

13. In order to determine th effectiveness of advance maintenance

---

* All depths cited herein are in feet below mean low water (mlw).

for any maintenance dredging project, the relation between shoaling characteristics of that project and project dimensions must first be determined. The shoaling characteristics of a project can usually be investigated as follows:

a. Analysis of maintenance dredging records from the Corps of Engineers Annual Reports (Phase 1).

b. Analysis of shoaling rates as determined from dredging records from the Corps of Engineers Annual Reports (Phase 1-Modified).

c. Analysis of shoaling rates as determined from periodic hydrographic surveys (Phase 2).

14. The analysis of maintenance dredging records from Corps Annual Reports (Phase 1) is the easiest to apply, but also the least accurate. The analysis of shoaling rates as determined from dredging records from the Corps Annual Reports (Phase 1-Modified) is an extension of Phase 1, but requires additional information. Analysis of shoaling rates as determined from periodic hydrographic surveys computes shoaling rates directly and is therefore the most accurate; but the surveys required are usually not available for the entire history of the project. The three approaches will be demonstrated with the example channel described in paragraph 12. The use of Phase 1 or Phase 1-Modified combined with Phase 2 analysis is required for predictive purposes.

## Phase 1

15. The annual report dredging data for the example channel presented in Table 1 are graphically displayed as dredging volume versus fiscal year in Figure 4. The variance in yearly dredging activity is quite large. Years in which no dredging occurred are plotted as zero. Another factor contributing to variances is that dredging periods which straddled two fiscal years, i.e., began in one fiscal year but ended in the next, are plotted as two separate dredging activities, rather than as one dredging activity as actually was the case. Inspection of Table 1 indicates that dredging activity may have straddled fiscal year boundaries during FY 1943-44, FY 1950-51, FY 1954-55, FY 1959-60, and

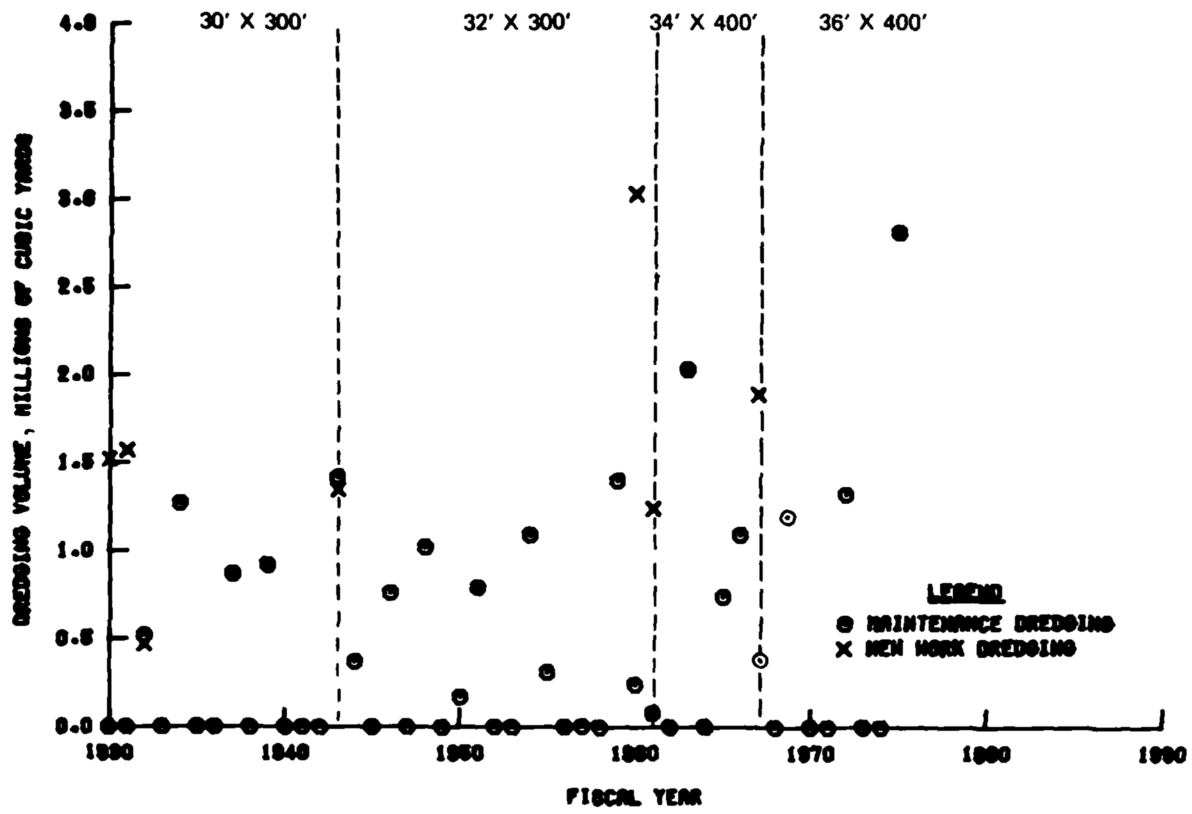



Figure 4. Example channel dredging history

FY 1965-66, resulting in two data points for one period of dredging activity.

16. In order to more quantitatively determine the relation between dredging requirements and channel size, a second plot of the same data is presented in Figure 5, where the annual maintenance dredging volumes are plotted against accumulated new work volume. In order to be as general as possible, accumulated new work is the parameter used to represent increasing channel dimensions. If the project is such that the channel width has not varied over several channel deepenings, then plots of dredging or shoaling versus depth can also be generated. A regression curve, $Y = AX^2 + BX$, is least-square fitted to the data as a guideline for the shoaling behavior (rate of dredging) as a function of channel dimensions. As can be seen from Figure 5, the regression curve is almost linear for the example project and indicates an average annual maintenance dredging volume of 0.30 million cu yd for the original project (30 × 300 ft). The average annual maintenance dredging volume is increased to 0.40 million cu yd for the 32- × 300-ft project, an increase of 33 percent compared with the 30- × 300-ft project. The average annual maintenance dredging volume is increased to 0.67 million cu yd for the 34- × 400-ft project, an increase of about 68 percent when compared with the 32- × 300-ft project. The average annual maintenance dredging volume is increased to 0.77 million cu yd for the 36- × 400-ft project, an increase of 13 percent when compared with the 34- × 400-ft project.

17. The above results indicate that increases in project depth of 2 ft caused increases in annual maintenance dredging of about 13 to 33 percent, while the deepening and widening of 2 ft and 100 ft, respectively, resulted in a substantial increase of about 68 percent. Therefore, a major portion of the 68 percent increase caused by the deepening and widening could reasonably be expected to have been caused by the widening alone. This is not an unexpected result, since the dredged volume would increase with the greater bottom area even if the shoaling rate (depth deposited/time) remained constant.

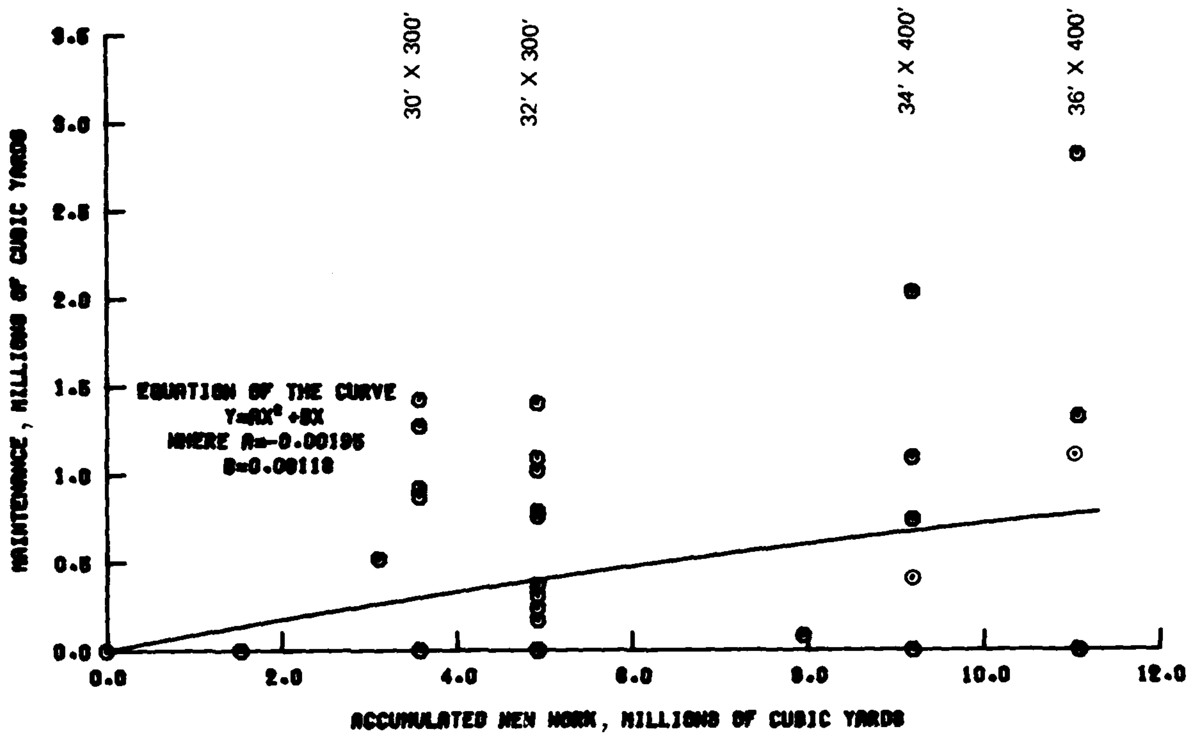



Figure 5. Example channel annual maintenance plotted as a function of accumulated new work volume

## Phase 1-Modified

18. The preceding analysis was based only on fiscal year dredging volumes from the Corps Annual Reports. If the actual dates of dredging activity are also provided in the Annual Reports or are available from district files, the analysis can be refined to increase its predictive capability by computing shoaling rates based on dredging volumes and the actual time intervals rather than intervals restricted to whole years as in Phase 1. For example, Table 2 gives the dates of dredging activity for the example navigation channel described previously. Using this information, the average shoaling rates based on dredging volumes and the associated time intervals can be computed as shown in Table 2. In order that the relation between shoaling and accumulated new work volumes (channel dimensions) can be determined as was done in Phase 1 previously, the average shoaling rate for each accumulated new work volume (channel dimension) is computed. For example, the average shoaling rate for the 32- × 300-ft channel (an accumulated new work volume of 4.91 million cu yd) is computed in the following manner. From Tables 1 and 2, the total volume of dredging to maintain the 32- × 300-ft channel (4.91 accumulated new work volume) was 5.86 million cu yd (0.76 + 1.02 + 0.96 + 1.40 + 1.64 + 0.08 = 5.86). From Table 2, the period of time in which the 32- × 300-ft channel existed was from 10 August 1943 to 2 March 1961 (17.55 yr). Therefore, the average shoaling rate based on dredging volumes for the 32- × 300-ft channel was 0.33 million cu yd per year (5.86 million cu yd/17.55 yr).

19. The average shoaling rate is computed for each of the different channel dimensions as was demonstrated for the 32- × 300-ft channel. The regression curve obtained using shoaling rates determined from Phase 1-Modified is shown in Figure 6. It should be noted that the average shoaling rates for each channel dimension were weighted according to the number of times the project was dredged for maintenance. The reason for weighting the shoaling rates is that the greater the number of times the project is dredged, the more likely the computed shoaling rates are representative of the actual shoaling rates. Therefore, for

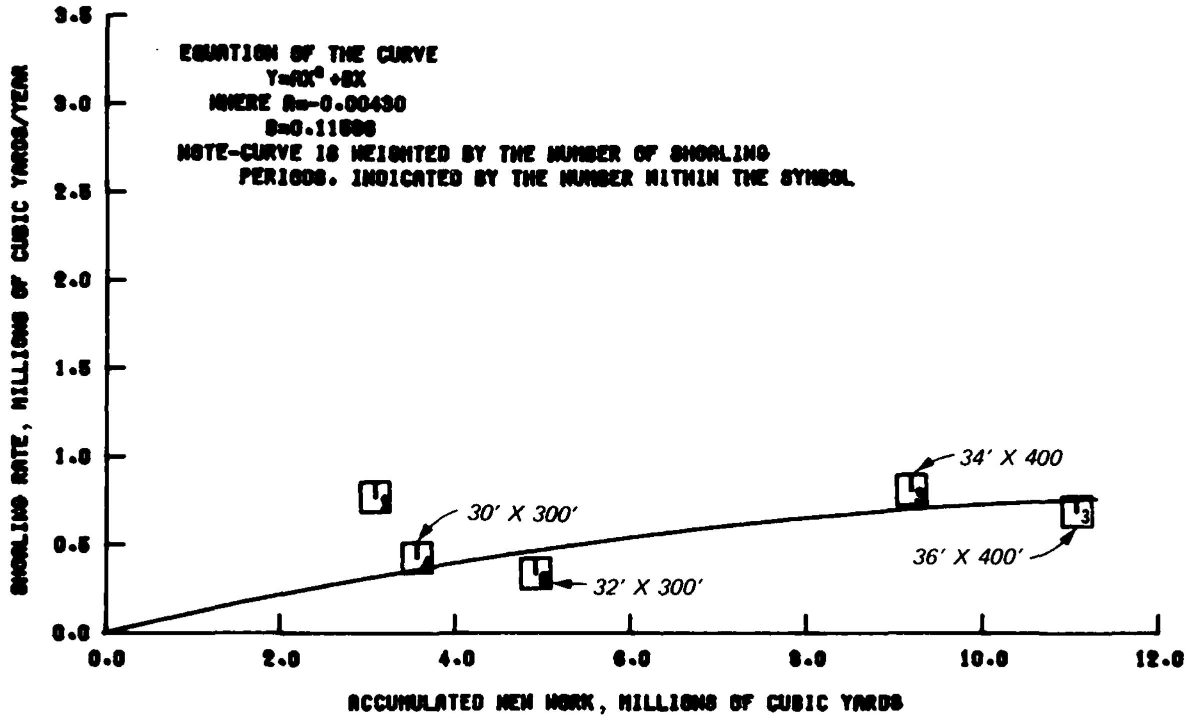



Figure 6. Example channel average shoaling rates (computed from dredging volumes) plotted as a function of accumulated new work volume

the regression curve in Figure 6, the average shoaling rate for the 30- × 300-ft channel was actually considered as four data points; the average shoaling rate for the 32- × 300-ft channel was considered as six data points; the average shoaling rate for the 34- × 400-ft channel was considered as three data points; and the average shoaling rate for the 36- × 400-ft channel was considered as three data points. Therefore, the 30- × 300-ft, 32- × 300-ft, 34- × 400-ft, and 36- × 400-ft channel average shoaling rates had weighting factors of 1.33, 2.00, 1.00, and 1.00, respectively. The resulting regression curve (Figure 6) indicates an average shoaling volume of 0.36 million cu yd/yr for the original project (30 × 300 ft). The average shoaling volume is increased to 0.47 million cu yd/yr for the 32- × 300-ft project, an increase of 31 percent compared with the 30- × 300-ft project. The average shoaling volume is increased to 0.70 million cu yd/yr for the 34- × 400-ft project, an increase of about 49 percent when compared with the 32- × 300-ft project. The average shoaling volume is increased to 0.76 million cu yd/yr for the 36- × 400-ft project, an increase of 9 percent when compared with the 34- × 400-ft project.

20. The above results indicate that increases in project depth of 2 ft caused increases in average shoaling volumes of about 9 to 31 percent, while the deepening and widening of 2 ft and 100 ft, respectively, resulted in a substantial increase of about 49 percent.

21. The regression curve obtained using Phase 1-Modified differs only slightly from the curve obtained using Phase 1 for the example channel. For the subsequent shoaling prediction the results from the Phase 1 analysis will be used.

## Phase 2

22. Phase 2 differs from Phases 1 and 1-Modified in that shoaling volumes are computed directly from hydrographic survey data rather than indirectly through dredging volumes. The use of survey sheets allows one to analyze the shoaling distribution within the project, i.e., the project can be segmented and the shoaling determined for each segment. Dredging data from annual reports are not usually broken down extensively.

The disadvantage with hydrographic survey data is that usually they are available only for the more recent history of the project. For the example channel, the hydrographic survey data are available only as far back as 1960. No survey data are available from 1930 to 1960. Phase 2 results, which provide shoaling rates for each of the selected segments within the project for the more recent conditions, will be coupled with the results provided by Phases 1 or 1-Modified to predict the effectiveness of advance maintenance dredging. The following survey data are available for the example project:

a. January 1961 - Predredge survey.
b. March 1961 - Postdredge survey.
c. October 1962 - Predredge survey.
d. February 1963 - Postdredge survey.
e. March 1965 - Predredge survey.
f. November 1965 - Postdredge survey.
g. January 1967 - Predredge survey.
h. June 1967 - Postdredge survey.
i. July 1968 - Predredge survey.
j. December 1968 - Postdredge survey.
k. December 1971 - Predredge survey.
l. June 1972 - Postdredge survey.
m. July 1974 - Predredge survey.
n. December 1974 - Postdredge survey.

23. Using these survey data, six shoaling periods (postdredge survey to following predredge survey) were considered, i.e., from March 1961 to October 1962 (19 months), from February 1963 to March 1965 (25 months), from November 1965 to January 1967 (14 months), from June 1967 to July 1968 (13 months), from December 1968 to December 1971 (36 months), and from June 1972 to July 1974 (23 months). The first three survey periods occurred when the authorized dimensions were 34 ft × 400 ft, and the second three periods occurred when the authorized dimensions were 36 ft × 400 ft.

24. The project, shown on the location map in Figure 7, was segmented into 10 equal 1-mile sections and the section shoaling rates for

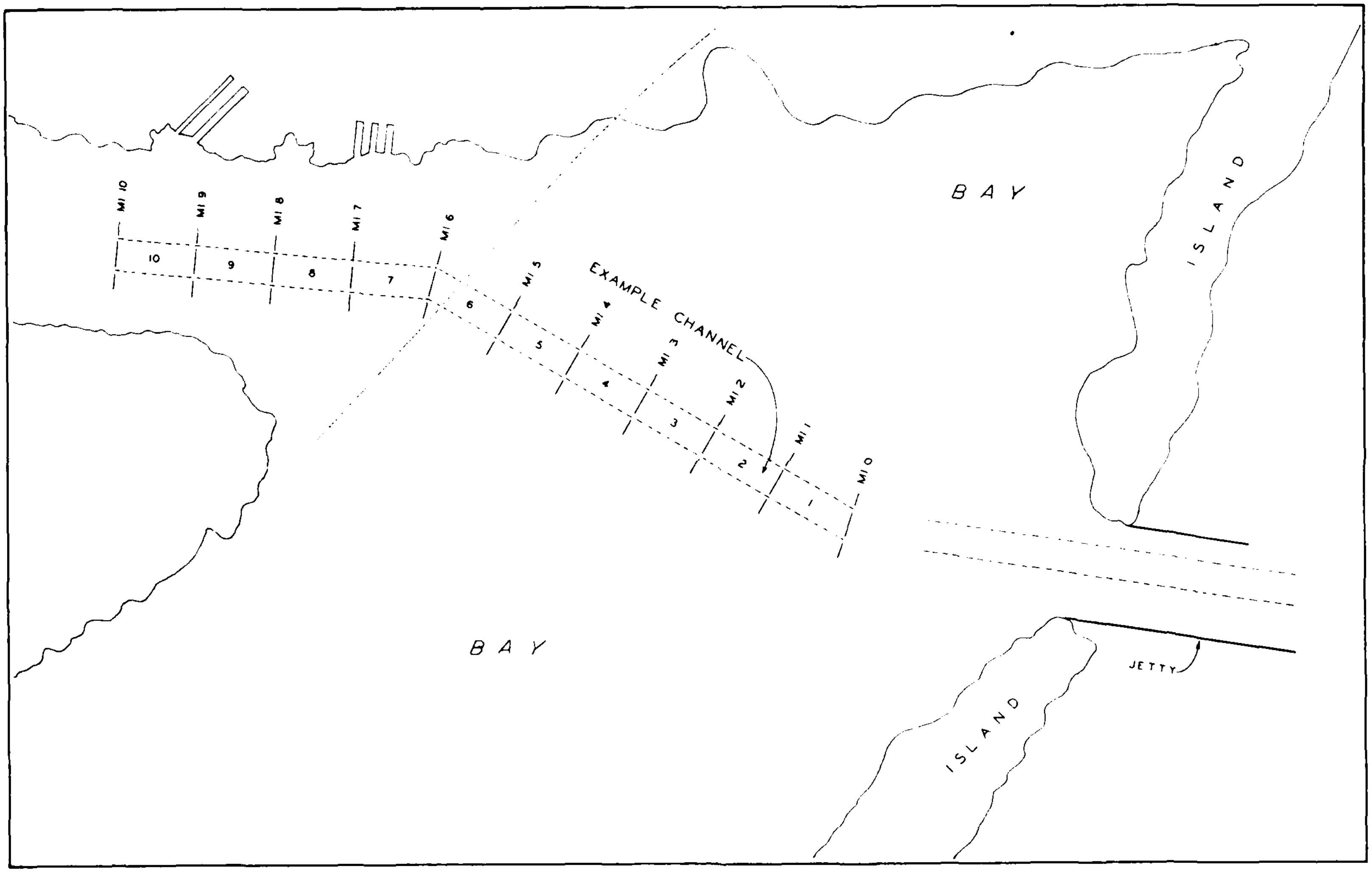



Figure 7. Example channel location map

each of the 6 shoaling periods were computed and are presented in Table 3. Project shoaling for the three periods with the 34-ft authorized depth, computed by Phase 2 analysis, totaled about 600, 620, and 660 thousand cu yd/yr for a time-weighted average of 625 thousand cu yd/yr. Project shoaling for the three periods with the 36-ft authorized depth, computed by Phase 2 analysis, were about 780, 740, 760 thousand cu yd/yr for a time-weighted average of 759 thousand cu yd/yr.

## Comparison of Results

25. The shoaling results for the example channel obtained from the regression curves of Phases 1 and 1-Modified and the direct computations of Phase 2 are summarized as follows:

| | Shoaling in Thousands of cu yd/yr for Channel Dimensions | | | |
|---|---|---|---|---|
| Phase | 30 × 300 ft | 32 × 300 ft | 34 × 400 ft | 36 × 400 ft |
| 1 | 300 | 401 | 673 | 770 |
| 1-Mod | 358 | 465 | 701 | 756 |
| 2 | -- | -- | 625 | 759 |

26. Results from the Phase 2 analysis indicate that the use of historical dredging volumes to determine the effect of increasing dimensions on shoaling rates was reasonable. If the Phase 2 analysis had yielded shoaling rates which differed significantly from Phase 1 or 1-Modified, a further exploration of the data to determine their adequacy would be required.

## Shoaling Predictions

27. Table 2 shows that the average dredging interval for the existing project is 3.0 yr (6.0 yr ÷ 2). Table 3 shows that the highest average shoaling rate of 1.6 ft per year for the existing project occurred in section 6. Therefore, the representative controlling depth for the existing project, assuming the full 2 ft of allowable dredging tolerance is used, can be determined as follows:

Shoaling in section 6 = 1.6 ft per year × 3.0 years = 4.8 ft

Controlling depth = 36 ft + 2 ft allowable dredging tolerance

- 4.8 ft shoaling = 33.2 ft

28. Based on the data in Table 3, the existing shoaling pattern for the example project is shown in Figure 8. Advance maintenance can be applied either to reduce dredging frequency while maintaining the controlling depth at 33.2 ft, or to increase the controlling depth to authorized depth (36 ft) while maintaining or reducing the dredging frequency. The procedure used to investigate these objectives will now be discussed.

29. The increase in the shoaling rate for the 2-ft depth increase from 34 to 36 ft (from 9,180 to 11,070 thousand cu yd accumulated new work) indicated by the Phase 1 regression curve was about 13 percent. The curve also indicates a decreasing rate of increase with depth. For the following evaluation of overdepth dredging, the increase in shoaling rate will be held constant at 13 percent per 2-ft increment rather than decreased. The resulting predictions should tend to be on the conservative side.

30. Using the 13 percent rate of increase for each 2-ft increment from 2 to 10 ft of advance maintenance (40- to 48-ft depth, including 2 ft of allowable dredging tolerance at each increment), the incremental shoaling rates for each of the 10 sections are:

| Depth ft | Predicted Incremental Shoaling Rates, ft/yr, for Sections | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Less than 38* | 0.5 | 0.7 | 0.8 | 0.9 | 1.2 | 1.6 | 1.4 | 1.2 | 0.8 | 0.5 |
| 38 to 40 | 0.6 | 0.8 | 0.9 | 1.0 | 1.4 | 1.8 | 1.6 | 1.4 | 0.9 | 0.6 |
| 40 to 42 | 0.7 | 0.9 | 1.0 | 1.1 | 1.6 | 2.0 | 1.8 | 1.6 | 1.0 | 0.7 |
| 42 to 44 | 0.8 | 1.0 | 1.1 | 1.2 | 1.8 | 2.3 | 2.0 | 1.8 | 1.1 | 0.8 |
| 44 to 46 | 0.9 | 1.1 | 1.2 | 1.4 | 2.0 | 2.6 | 2.3 | 2.0 | 1.2 | 0.9 |
| 46 to 48 | 1.0 | 1.2 | 1.4 | 1.6 | 2.3 | 2.9 | 2.6 | 2.3 | 1.4 | 1.0 |

* Shoaling rates for this depth are taken directly from Table 3 for the 36-ft project depth.

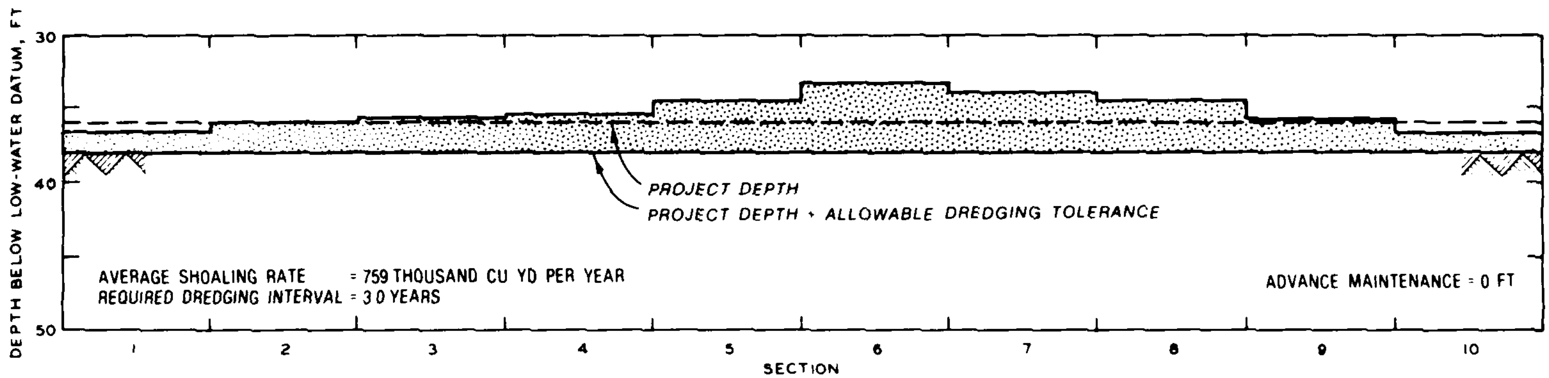



Figure 8. Existing shoaling pattern for example channel

The above incremental shoaling rates will be applied to all advance maintenance evaluations of the example project.

## Reduction in Dredging Frequency While Maintaining Controlling Depth

31. Advance maintenance of 2, 4, 6, 8, and 10 ft along the entire length of the channel will now be considered.

### Two feet of advance maintenance

32. Two feet of advance maintenance will increase the after-dredging depth to 40 ft (36 ft authorized plus 2 ft advance maintenance plus 2 ft allowable dredging tolerance). The first section to be evaluated must be the section with the highest shoaling rate, section 6. Since the after-dredging depth is set at 40 ft, and the shoaling rate for section 6 from 40 to 38 ft is 1.8 ft/yr, section 6 will shoal from 40 to 38 ft in 1.1 yr (2 ft/1.8 ft per yr). Since the shoaling rate for section 6 from 38 to 33.2 ft (controlling depth) is 1.6 ft/yr, section 6 will shoal from 38 to 33.2 ft in 3.0 yr (4.8 ft/1.6 ft per yr). Therefore, section 6 will shoal from 40 to 33.2 ft in 4.1 yr (1.1 yr + 3.0 yr), which then becomes the time interval to be used in evaluating the remaining nine sections. Section 1 will shoal from 40 to 38 ft at the rate of 0.6 ft/yr in 3.3 yr (2 ft/0.6 ft per yr). For the remaining 0.8 yr (total = 4.1 yr), section 1 will shoal above 38 ft depth at the rate of 0.5 ft/yr, or 0.4 ft (0.8 yr × 0.5 ft/yr). Total shoaling for section 1 in 4.1 yr equals 2.0 ft (40 to 38 ft) plus 0.4 ft (38.0 to 37.6) or 2.4 ft. Since the bottom area is known, the shoaling volume for the 4.1-yr period can also be determined, excluding the amount deposited outside the channel prism on the side slopes. For section 1 this is 188 thousand cu yd (400 ft × 5280 ft × 2.4 ft/27 $ft^3$ per $yd^3$). The same procedure can be followed for sections 2, 3, 4, 5, 7, 8, 9, and 10, resulting in the shoaling pattern shown Plate 1a profile. The overall average annual shoaling rate listed in Plate 1a profile is determined by computing the volume of shoaling in each of the 10 sections, summing, and then dividing by the computed dredging interval (4.1 yr).

Four feet of advance maintenance

33. Four feet of advance maintenance will increase the postdredge depth to 42 ft (36 ft authorized plus 4 ft advance maintenance plus 2 ft allowable dredging tolerance). As was the case for 2 ft advance maintenance, the first section to be evaluated is section 6. Since the postdredge depth is 42 ft, and the shoaling rate for section 6 from 42 to 40 ft is 2.0 ft/yr, section 6 will shoal from 42 to 40 ft in 1.0 yr (2.0 ft/2.0 ft per yr). As previously determined (paragraph 32), section 6 will shoal from 40 to 38 ft in 1.1 yr and from 38 to 33.2 ft in 3.0 yr. Section 6 will shoal from 42 to 33.2 ft in 5.1 yr (1.0 yr + 1.1 yr + 3.0 yr), which becomes the time interval to be used for the remaining nine sections. Section 1 will shoal from 42 to 40 ft at the rate of 0.7 ft/yr in 2.9 yr (2.0 ft/0.7 ft per yr). For the remaining 2.2 yr (total = 5.1 yr) section 1 will shoal at the rate of 0.6 ft/yr or 1.3 ft (2.2 yr × 0.6 ft/yr). Total shoaling for section 1 in 5.1 yr equals 2.0 ft (42- to 40-ft depth) plus 1.3 ft (40- to 38.7-ft depth), or 3.3 ft. Shoaling volume for the 5.1-yr interval is 258 thousand cu yd (3.3 ft × 400 ft × 5280 ft/27 ft$^3$ per yd$^3$). The same procedure can be followed for sections 2, 3, 4, 5, 7, 8, 9, and 10, resulting in the shoaling pattern shown in Plate 1b profile.

Six feet of advance maintenance

34. Six feet of advance maintenance will increase the after-dredging depth to 44 ft (36 ft authorized plus 6 ft advance maintenance plus 2 ft allowable dredging tolerance). Since the postdredge depth is 44 ft and the shoaling rate for section 6 from 44 to 42 ft is 2.3 ft/yr, section 6 will shoal from 44 to 42 ft in 0.9 yr (2.0 ft/2.3 ft per yr). As previously determined in paragraph 33, section 6 will shoal from 42 to 33.2 ft in 5.1 yr. Section 6 will therefore shoal from 44 to 33.2 ft in 6.0 yr (5.1 yr + 0.9 yr), which becomes the time interval to be used for the remaining sections. Section 1 will shoal from 44 to 42 ft at the rate of 0.8 ft/yr in 2.5 yr (2.0 ft/0.8 ft per yr) and from 42 to 40 ft at the rate of 0.7 ft/yr in 2.9 yr (2.0 ft/0.7 ft per yr). For the remaining 0.6 yr (total = 6.0 yr) section 1 will shoal at the rate of 0.6 ft/yr, or 0.4 ft (0.6 yr × 0.6 ft/yr). Total shoaling for

section 1 in 6.0 yr equals 2.0 ft (44- to 42-ft depth) plus 2.0 ft (42- to 40-ft depth) plus 0.4 ft (40- to 39.6-ft depth), or 4.4 ft. Shoaling volume for the 6.0-yr interval is 344 thousand cu yd (400 × 5280 ft × 4.4 ft/27 $ft^3$ per $yd^3$). The same procedure can be followed for sections 2, 3, 4, 5, 7, 8, 9, and 10, resulting in the shoaling pattern shown in Plate 1c profile.

Eight feet of advance maintenance

35. Eight feet of advance maintenance will increase the after-dredging depth to 46 ft (36 ft authorized plus 8 ft advance maintenance plus 2 ft allowable dredging tolerance). The shoaling rate for section 6 from 46- to 44-ft depth is 2.6 ft/yr, which means section 6 will shoal from 46- to 44-ft depth in 0.8 yr (2.0 ft/2.6 ft per yr). As previously determined in paragraph 34, section 6 will shoal from 44 to 33.2 ft in 6.0 yr. Section 6 will therefore shoal from 46 to 33.2 ft in 6.8 yr (0.8 yr + 6.0 yr), which becomes the time interval to be used for the remaining nine sections. Section 1 will shoal from 46- to 44-ft depth at the rate of 0.9 ft/yr in 2.2 yr (2.0 ft/0.9 ft per yr) and from 44- to 42-ft depth at the rate of 0.8 ft/yr in 2.5 yr (2.0 ft/0.8 ft per yr). For the remaining 2.1 yr (total = 6.8 yr), section 1 will shoal at the rate of 0.7 ft/yr, or 1.5 ft (2.1 yr × 0.7 ft per yr). Total shoaling for section 1 in 6.8 yr equals 2.0 ft (46- to 44-ft depth) plus 2.0 ft (44- to 42-ft depth) plus 1.5 ft (42- to 40.5-ft depth), or 5.5 ft. Shoaling volume for the 6.8-yr interval is 430 thousand cu yd (400 ft × 5280 ft × 5.5 ft/27 $ft^3$ per $yd^3$). The same procedure can be followed for sections 2, 3, 4, 5, 7, 8, 9, and 10, resulting in the shoaling pattern shown in Plate 1d profile.

Ten feet of advance maintenance

36. Ten feet of advance maintenance will increase the after-dredging depth to 48.0 ft (36 ft authorized plus 10 ft advance maintenance plus 2 ft allowable dredging tolerance). The shoaling rate for section 6 from 48- to 46-ft depth is 2.9 ft/yr, which means section 6 will shoal from 48- to 46-ft depth in 0.7 yr (2.0 ft/2.9 ft per yr). As previously determined in paragraph 35, section 6 will shoal from 46 to 33.2 ft in 6.8 yr. Section 6 will therefore shoal from 48 to 33.2 ft in 7.5 yr

(0.7 yr + 6.8 yr), which is also the time interval to be used for the remaining nine sections. Section 1 will shoal from 48- to 46 ft depth at the rate of 1.0 ft/yr in 2.0 yr (2.0 ft/1.0 ft per yr) and from 46- to 44-ft depth at the rate of 0.9 ft/yr in 2.2 yr (2.0 ft/0.9 ft per yr) and from 44- to 42-ft depth at the rate of 0.8 ft/yr in 2.5 yr (2.0 ft/0.8 ft per yr). For the remaining 0.8 yr (total = 7.5 yr), section 1 will shoal at the rate of 0.7 ft/yr, or 0.6 ft (0.8 yr × 0.7 ft/yr). Total shoaling for section 1 in 7.5 yr equals 2.0 ft (48- to 46-ft depth) plus 2.0 ft (46- to 44-ft depth) plus 2.0 ft (44- to 42- ft depth) plus 0.6 ft (42- to 41.4-ft depth), or 6.6 ft. Shoaling volume for the 7.5-yr interval is 516 thousand cu yd (400 ft × 5280 ft × 6.6 ft/27 $ft^3$ per $yd^3$). The same procedure is followed for sections 2, 3, 4, 5, 7, 8, 9, and 10, resulting in the shoaling pattern shown in Plate 1e profile.

37. The average shoaling rates and required dredging intervals for advance maintenance dredging from 2 to 10 ft are shown as follows:

| Advance Maintenance ft | Average Shoaling Rate Thousands of cu yd/yr | Required Dredging Interval yr |
|---|---|---|
| 0 (existing) | 759 | 3.0 |
| 2 | 800 | 4.1 |
| 4 | 858 | 5.1 |
| 6 | 917 | 6.0 |
| 8 | 986 | 6.8 |
| 10 | 1,043 | 7.5 |

As can be seen, any increase in the required dredging interval is accompanied by the undesirable increase in shoaling rate. Since the shoaling rate for the example channel exhibits higher shoaling rates in sections 5 through 8 and lesser shoaling rates in the remaining sections, various combinations of advance maintenance will now be investigated with the intent of keeping the increased shoaling rates which accompany the example channel advance maintenance to a minimum.

Varied advance maintenance

38. A procedure that is termed "varied advance maintenance" in this report will be investigated here. Varied advance maintenance is defined as the application of different amounts of advance maintenance

along a dredged channel, according to need. For the example channel, the shoaling rates of the 10 sections are divided into high-rate-of-shoaling and low-rate-of-shoaling sections. Sections 5 through 8 are considered to have high rates of shoaling, and sections 1, 2, 3, 4, 9, and 10 are considered to have low rates of shoaling. The advance maintenance applied to sections 5 through 8 (high shoaling rates) will be greater than the advance maintenance applied to sections 1, 2, 3, 4, 9, and 10 (low shoaling rates).

39. The computational procedure for the varied advance maintenance schemes are the same as previously described, except that the after-dredging depths in the high-rate-of-shoaling sections and the low-rate-of shoaling sections are different because the amounts of advance maintenance are different. For example a scheme with 6 ft advance maintenance in the high-rate-of-shoaling sections and 4 ft advance maintenance in the low-rate-of-shoaling sections has an after-dredging depth in sections 5 through 8 of 44 ft (36 ft authorized plus 6 ft advance maintenance plus 2 ft allowable dredging tolerance) and in sections 1, 2, 3, 4, 9, and 10 of 42 ft (36 ft authorized plus 4 ft advance maintenance plus 2 ft allowable dredging tolerance).

40. The shoaling patterns for 2 ft advance maintenance in the high-shoaling-rate sections and 2 or 0 ft advance maintenance in the low-shoaling-rate sections are shown in Plate 2. The shoaling patterns for 4 ft advance maintenance in the high-shoaling-rate sections and 4, 2, or 0 ft advance maintenance in the low-shoaling-rate sections are shown in Plate 3. The shoaling patterns for 6 ft advance maintenance in the high-shoaling-rate sections and 6, 4, 2, or 0 ft advance maintenance in the low-shoaling-rate sections are shown in Plate 4. It should be noted that the shoaling pattern for 6 ft advance maintenance in the high-shoaling-rate sections and no advance maintenance in the remaining sections coupled with the 6-yr dredging interval, shown in Plate 4, resulted in depths in sections 4 and 9 slightly less than the controlling depth of 33.2 ft. The shoaling patterns for 8-ft advance maintenance in the high-shoaling-rate sections and 8, 6, 4, or 2 ft advance maintenance

in the low-shoaling-rate sections are shown in Plate 5. The shoaling patterns for 10 ft advance maintenance in the high-shoaling-rate sections and 10, 8, 6, 4, or 2 ft advance maintenance in the low-shoaling-rate sections are shown in Plate 6. It should be noted that the shoaling pattern for 10 ft advance maintenance in the high-shoaling-rate sections and 2 ft advance maintenance in the remaining sections coupled with the 6-yr dredging interval, shown in Plate 6, resulted in a depth in section 4 slightly less than the controlling depth of 33.2 ft. The average shoaling rates and required dredging intervals for each of the above advance maintenance schemes are summarized as follows:

| Advance Maintenance ft | Average Shoaling Rate Thousands of cu yd/yr | Required Dredging Interval yr |
|---|---|---|
| 0 (existing) | 759 | 3.0 |
| 2 | 800 | 4.1 |
| 0 and 2 | 773 | 4.1 |
| 4 | 858 | 5.1 |
| 2 and 4 | 820 | 5.1 |
| 0 and 4 | 798 | 5.1 |
| 6 | 917 | 6.0 |
| 4 and 6 | 876 | 6.0 |
| 2 and 6 | 842 | 6.0 |
| 0 and 6 | 820 | 6.0 |
| 8 | 986 | 6.8 |
| 6 and 8 | 933 | 6.8 |
| 4 and 8 | 902 | 6.8 |
| 2 and 8 | 871 | 6.8 |
| 10 | 1,043 | 7.5 |
| 8 and 10 | 1,001 | 7.5 |
| 6 and 10 | 960 | 7.5 |
| 4 and 10 | 924 | 7.5 |
| 2 and 10 | 895 | 7.5 |

41. For a given dredging interval, the application of varied advance maintenance can result in a significant reduction in the dredging volume compared with the same depth of advance maintenance applied uniformly to the channel. Figure 9 presents the shoaling rate-dredging interval curve developed from the most efficient of the combinations of

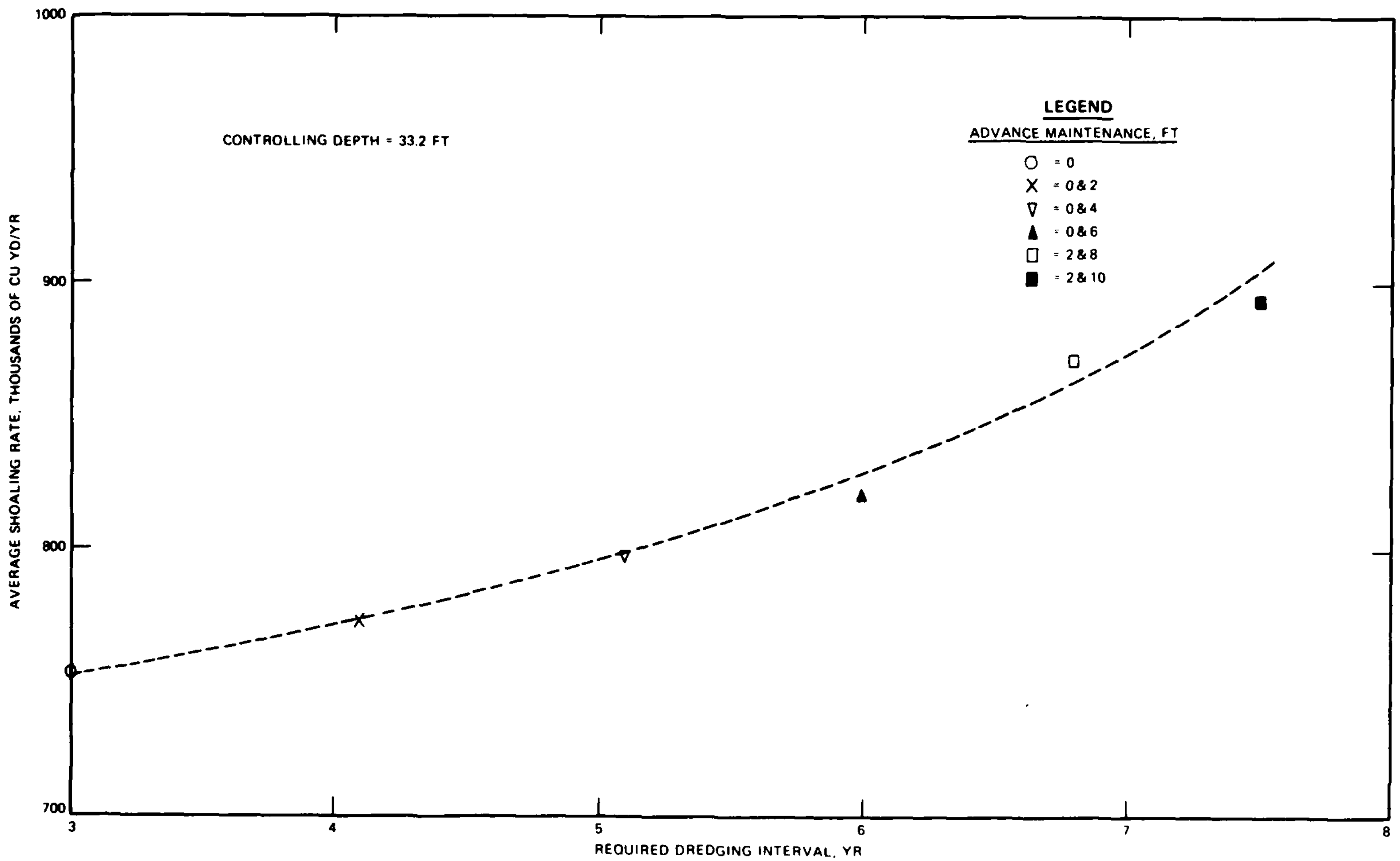



Figure 9. Example channel dredging interval-shoaling relation for various schemes of advance maintenance with a controlling depth of 33.2 ft

advance maintenance investigated for the example project. This curve would be used for any subsequent economic analysis to determine the applicability of advance maintenance.

## Increase in Controlling Depth While Maintaining or Reducing Dredging Frequency

42. For the example project the existing dredging interval is 3 yr, but the controlling depth (at section 6) is only 33.2 ft, which is considerably less than the 36-ft authorized depth. The objective here is to determine the amount of advance maintenance required to increase the controlling depth to 36 ft while maintaining or reducing the required dredging frequency. Advance maintenance of 2, 4, 6, 8, and 10 ft will be evaluated. The shoaling rates and the computational procedure are the same as described previously. The only difference is that the controlling depth is 36 ft rather than 33.2 ft. The resulting shoaling patterns for 0, 2, 4, 6, 8, and 10 ft advance maintenance are shown in Plates 7-12. The average shoaling rate and required dredging intervals are summarized as follows:

| Advance Maintenance ft | Average Shoaling Rate Thousands of cu yd/yr | Required Dredging Interval yr |
|---|---|---|
| 0 | 759 | 1.3 |
| 2 | 829 | 2.4 |
| 0 and 2 | 783 | 2.4 |
| 4 | 894 | 3.4 |
| 2 and 4 | 854 | 3.4 |
| 6 | 961 | 4.3 |
| 4 and 6 | 920 | 4.3 |
| 2 and 6 | 880 | 4.3 |
| 8 | 1,030 | 5.1 |
| 6 and 8 | 986 | 5.1 |
| 4 and 8 | 943 | 5.1 |
| 10 | 1,099 | 5.8 |
| 8 and 10 | 1,054 | 5.8 |
| 6 and 10 | 1,015 | 5.8 |
| 4 and 10 | 969 | 5.8 |

43. As can be seen from the results, for a given dredging interval the application of varied advance maintenance can result in a significant reduction in the dredging volume compared with the same depth of advance maintenance applied uniformly to the channel. Figure 10 represents the shoaling-rate dredging interval curve developed from the most efficient of the schemes investigated for the example project. The curve would be used for any subsequent economic analysis to determine the applicability of advance maintenance.

44. At the present time very limited use of varied advance maintenance procedures exists. As these procedures may be applied to navigation channels, the need to continuously update predictions is important. The variable depths could change the shoaling rates in various portions of the channel to the extent that the effectiveness of advanced maintenance could change.

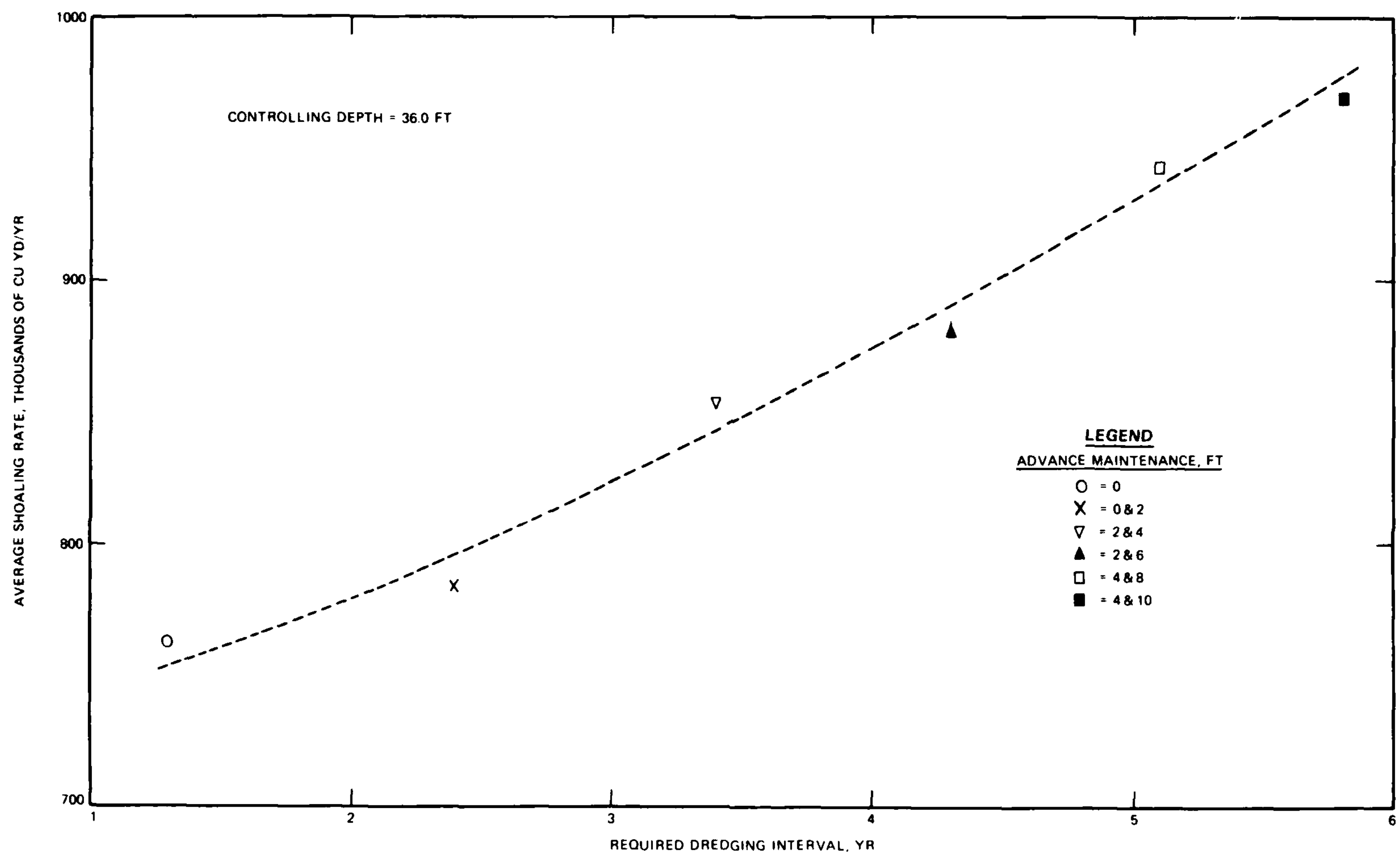



Figure 10. Example channel dredging interval-shoaling relation for various schemes of advance maintenance with a controlling depth of 36.0 ft

## PART III: ANALYSES OF SELECTED GALVESTON BAY PROJECTS

45. The shoaling analyses described in PART II of this report will now be applied to selected navigation projects in Galveston Bay, Texas. The Galveston Channel, Texas City Channel, and Houston Ship Channel (Phases 1 and 1-Modified only) will be analyzed and shoaling predictions made for various amounts of advance maintenance dredging.

### Bay Description

46. Galveston Bay, located in the southeastern part of Texas on the Gulf of Mexico (Figure 11), is approximately 60 miles west of Port Arthur, Texas, and 50 miles south of Houston, Texas. With the exception of the area between Galveston Island and Bolivar Peninsula, known as Bolivar Roads, the bay is relatively shallow and varies generally from 7 to 9 ft in depth, except for the deepened channels that are maintained by dredging. Bolivar Roads is connected to the various ports in or near Galveston Bay by Galveston, Houston Ship, and Texas City Channels and is connected to the Gulf of Mexico by the Galveston Harbor entrance or jetty channel. The improvements to the natural pass between Galveston Bay and the Gulf of Mexico include a jettied entrance channel from deep water in the gulf to Bolivar Roads, a distance of about 7 miles, and north and south rock jetties, about 5 and 7 miles long, respectively.

47. Currents in the channels and bays are largely the result of Gulf of Mexico tides. The mean diurnal range is about 2 ft in the Gulf of Mexico at Galveston Bay and about 0.5 ft in the San Jacinto River and Buffalo Bayou. The normal water-surface elevation at the entrance to Galveston Bay has been lowered by amounts up to 4.3 ft below mean low tide by strong north winds in the winter season, and has been raised by amounts up to 15 ft above mean low tide by tropical hurricanes which approach from the south, usually in late summer or early fall.

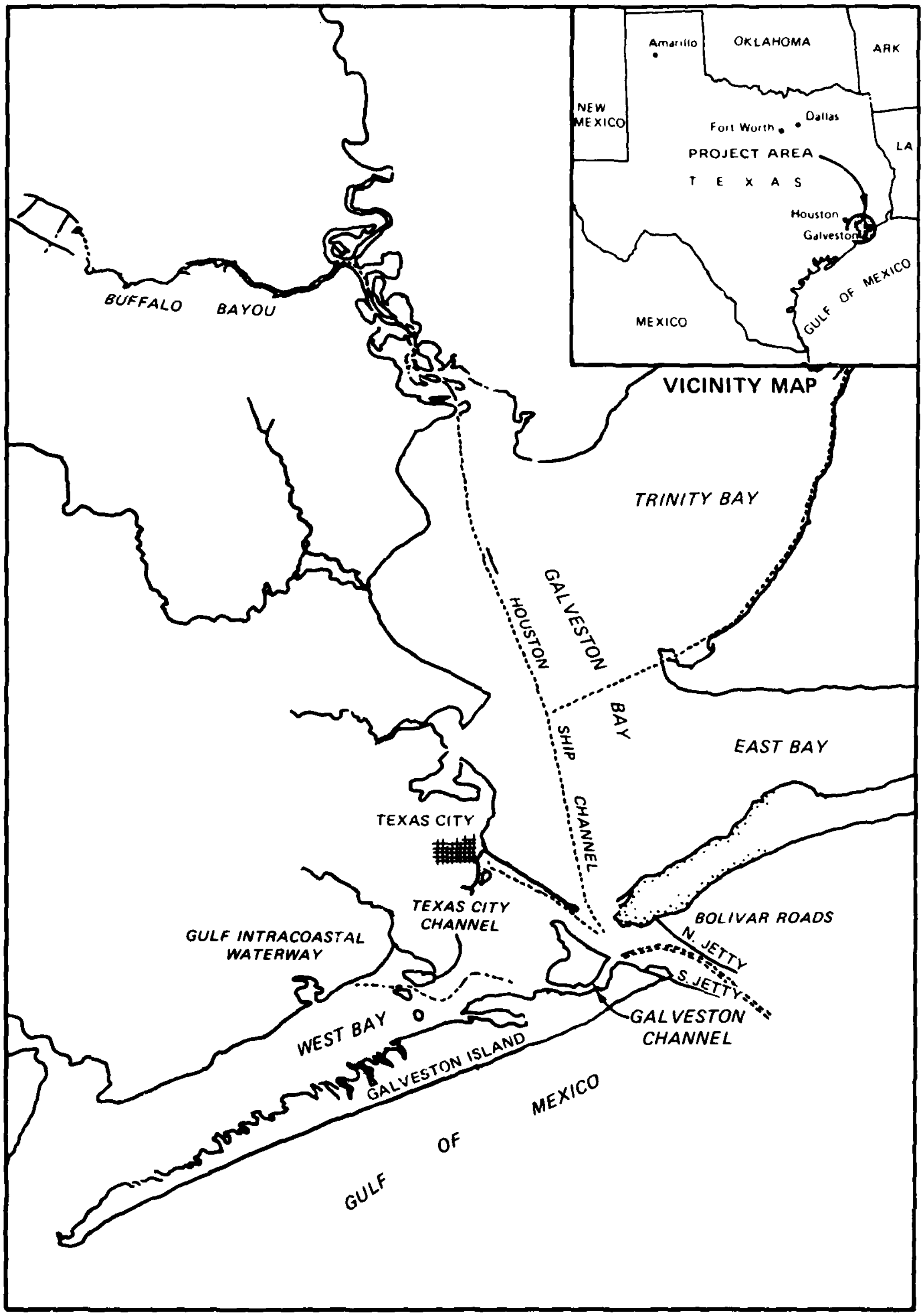



Figure 11. Location map

## Galveston Channel

48. Galveston Channel, located between Pelican Island and the Galveston waterfront (see Figure 12), was originally authorized by Congress in 1886. The natural condition consisted of a narrow channel with depths generally between 20 and 30 ft. Between 1905 and 1913, the project was deepened to a depth of 30 ft at mlw with a 1200-ft width. By 1940, the depths were being maintained between 32 and 34 ft. The predredge and postdredge survey sheets for Galveston Channel from 1960 to 1975, obtained from the Galveston District, indicated that from 1960 to 1962 the contract dredging depths were 34 ft at mlw plus 2 ft allowable overdepth and no advance maintenance; from 1962 through 1966, the depths were 34 ft at mlw plus 2 ft allowable dredging tolerance and 2 ft advance maintenance; and from 1966 through 1974, the depths were 36 ft at mlw plus 3 ft advance maintenance plus 2 ft allowable dredging tolerance. These design depths and the actual average postdredge depths for this period are shown in Plate 13. The channel depth is presently authorized for 40 ft at mlw plus 3 ft advance maintenance plus 2 ft allowable dredging tolerance, but definitive results from this recent depth increase will not be available for several years.

### Phase 1

49. Using the procedures described in PART II for Phase 1 analysis, the annual report dredging data for Galveston Channel are tabulated in Table 4 and graphically displayed in Plate 14 as maintenance dredging volume versus fiscal year. The second plot of the data, annual maintenance versus channel dimensions (accumulated new work), is presented in Plate 15. A 2nd degree regression curve, fitted to the second plot, serves as a guideline for the shoaling behavior as a function of channel dimensions. For Galveston Channel, since the increases in channel dimensions involve only increases in depth, not widening, the regression curve describes the relation of channel depth to required dredging

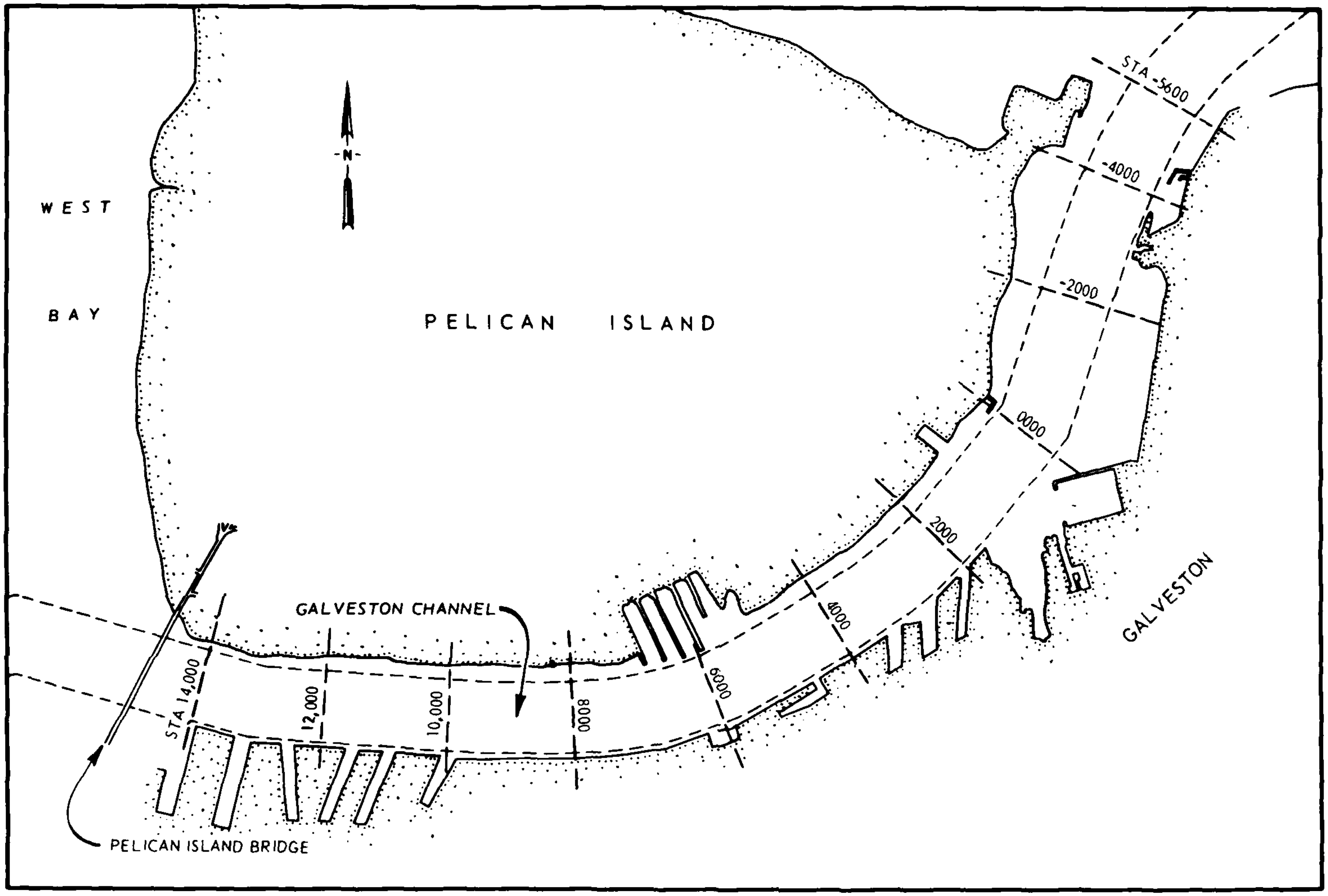



Figure 12. Galveston Channel location map

volume. The regression curve indicates the required dredging volumes for the Galveston Channel as follows:

| Project | Total Depth* | Required Dredging Volume, Millions of cu yd/yr | Percent Change** |
|---|---|---|---|
| 30 × 1200 | 32 | 1.87 | |
| 32 × 1200 | 34 | 1.94 | +4 |
| 34 × 1200 | 36 | 1.93 | -1 |
| 34 × 1200 | 38 | 1.90 | -2 |
| 36 × 1200 | 41 | 1.71 | -10 |

* Includes allowable dredging tolerance and advance maintenance.

** Compared with the immediately previous project.

50. The above results indicate that increases in the project depth of Galveston Channel have not caused increases in the overall project shoaling and also that the period which included 3 ft of advance maintenance dredging did not involve increased overall dredging. In fact, the results indicate that after deepening beyond 32 ft, average annual maintenance requirements actually decreased slightly. It is possible that other factors not addressed by this analysis such as differing maintenance practices, stabilization of Pelican Island, changes in traffic density and draft of vessels, or changes in sediment loading to Galveston Channel could have affected shoaling.

Phase 1-Modified

51. The preceding analysis was based only on fiscal year dredging volume from the Corps Annual Reports. Since for the Galveston Channel project the dates of dredging activity are also provided in the Annual Reports, the analysis was refined to enhance its predictive capability by computing shoaling rates based on dredging volumes and the actual time intervals rather than intervals restricted to whole years as in Phase 1. The shoaling rates based on dredging volumes for each shoaling interval are shown in Table 5. Using the procedure described in paragraphs 18 and 19 in PART II results in the regression curve shown

in Plate 16, which indicates the shoaling rates for the Galveston Channel as follows:

| Project | Total Depth* | Shoaling Rate Millions of cu yd/yr | Percent Change** |
|---|---|---|---|
| 30 × 1200 | 32 | 1.94 | |
| 32 × 1200 | 34 | 2.02 | +4 |
| 34 × 1200 | 36 | 2.01 | 0 |
| 34 × 1200 | 38 | 1.98 | -1 |
| 36 × 1200 | 41 | 1.78 | -10 |

* Includes allowable dredging tolerance and advance maintenance.

** Compared with the immediately previous project.

52. The above results, as was the case for Phase 1 analysis, indicate that increases in the project depth of Galveston Channel have not caused increases in the overall project shoaling and that 3 ft of advance maintenance dredging did not result in increased overall shoaling. Again, the results indicate that after deepening beyond 32 ft, maintenance dredging slightly decreased.

Phase 2

53. Hydrographic survey data were available from the Galveston District from 1960 through 1975. Phase 2 results will be compared with results obtained by Phases 1 and 1-Modified and will be used to determine the shoaling rates along Galveston Channel.

54. The survey data associated with the dredging activity occurring during May-December 1960; January-July 1962; April-May 1964; June 1971-October 1972; and January-June 1974 were available from the Galveston District. Using these survey data, the project was segmented into 10 sections (Figure 12), and the section shoaling rate for each the shoaling periods was computed as shown in Table 6. Project shoaling for the one period with the 34-ft authorized depth plus 2 ft of allowable overdepth was 1.79 million cu yd/yr. Project shoaling for the shoaling periods with an authorized depth of 34 ft plus 2 ft of

allowable dredging tolerance and 2 ft of advance maintenance averaged 1.78 million cu yd/yr. The averaging technique applied was to determine the time-weighted average for each section, then sum the section averages to obtain the total. For example, the section average for section _ was determined as follows:

$$\text{Section 1 average} = \left(190 \times \frac{25}{49}\right) + \left(283 \times \frac{13}{49}\right) + \left(246 \times \frac{11}{49}\right)$$

$$= 227 \text{ thousand cu yd/yr}$$

The section 5 average was computed as follows:

$$\text{Section 5 average} = \left(139 \times \frac{36}{47}\right) + \left(172 \times \frac{11}{47}\right)$$

$$= 147 \text{ thousand cu yd/yr}$$

The section averaging allows one to compute a total project average even though the entire length of the project was not dredged each time dredging occurred, as was the case for Galveston Channel during 1962 through 1965. It should be noted that whenever a project is analyzed in which the same length of project is dredged each time, it makes no difference whether the sections are averaged first and then totaled or whether the shoaling for each period is totaled and then averaged. Project shoaling for the four shoaling periods with an authorized depth of 36 ft plus 2 ft allowable dredging tolerance and 3 ft of advance maintenance were 1.81, 1.76, 1.82, and 1.87 million cu yd/yr for a time-weighted average of 1.81 million cu yd/yr.

55. Both Phases 1 and 1-Modified analyses of dredging data indicated no increase in shoaling when the channel was deepened from 34 to 36 ft, and also no increase in shoaling after 3 ft of advance maintenance was added to the 36-ft authorized depth channel. Phase 2 shoaling analysis agrees with the Phase 1 and 1-Modified results, as shown below:

| Shoaling in Thousands of cu yd/yr | | | | | |
|---|---|---|---|---|---|
| | Channel Depth, ft* | | | | |
| Phase | 30 | 32 | 34 | 34** | 36† |
| 1 | 1,870 | 1,940 | 1,930 | 1,900 | 1,710 |
| 1-Mod | 1,940 | 2,020 | 2,010 | 1,980 | 1,780 |
| 2 | -- | -- | 1,788 | 1,781 | 1,811 |

* Channel width - 1200 ft for all depths.
** With 2 ft advance maintenance.
† With 3 ft advance maintenance.

Therefore, it would be projected that increased channel depth would not increase the average annual maintenance requirement. Thus, it is shown a priori that calculations for increased advance maintenance will indicate no change in annual dredging volumes.

56. The average dredging interval for the existing channel, determined from the data in Table 5 (see "Shoaling Inverval" column), was 2.51 yr. Based on the shoaling rates from Table 6, the existing shoaling pattern at 2.51 yr after dredging is shown in Figure 13, indicating a controlling depth of 34.0 ft (in section 1).

Shoaling predictions

57. The controlling depth, which occurs in section 1, is assumed to be 34.0 ft to agree with the shoaling pattern in Figure 13. Increased advance maintenance can be evaluated either to reduce the dredging frequency while maintaining the 34.0-ft controlling depth in section 1 or to increase the controlling depth to 36 ft (authorized depth) while maintaining or reducing the frequency of dredging.

58. The existing conditions shoaling rates for sections 1 to 10 (Table 6) will be used for evaluation of 5, 6, and 9 ft of advance maintenance.

Reduction in dredging frequency while maintaining controlling depth

59. Increased advance maintenance of 5, 7, and 9 ft along the entire length of the channel will be investigated. Varied advance maintenance (lesser amounts of advance maintenance in the low shoal sections than in the high shoal sections) will also be investigated.

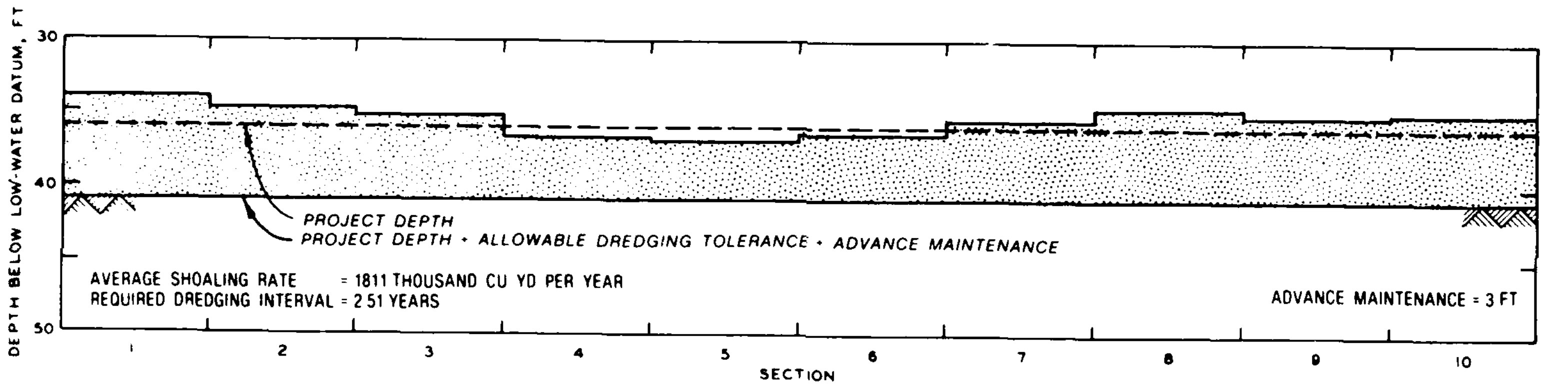



Figure 13. Galveston Channel existing shoaling pattern

60. Five feet of advance maintenance will increase the after-dredging depth to 43.0 ft (36 ft authorized depth plus 5 ft advance maintenance plus 2 ft allowable dredging tolerance). The first section which requires evaluation is the controlling section 1. Since the after-dredging depth is 43 ft and the shoaling rate for section 1 is 2.8 ft/yr, the section will shoal from 43.0 to 34.0 ft in 3.21 yr, which is also the time interval to be used for the remaining sections. The resulting shoaling pattern is shown in Plate 17a profile.

61. Seven feet of advance maintenance will increase the after-dredging depth to 45.0 ft (36 ft authorized plus 7 ft advance maintenance plus 2 ft allowable dredging tolerance). Section 1 will shoal from 45 to 35.1 ft in 3.93 yr. The resulting shoaling pattern is shown in Plate 18a profile.

62. Nine feet of advance maintenance will increase the after-dredging depth of 47.0 ft (36 ft authorized depth plus 9 ft advance maintenance plus 2 ft allowable dredging tolerance). Section 1 will shoal from 47 ft to 35.1 ft in 4.64 yr. The resulting shoaling pattern is shown in Plate 19a profile.

63. Since shoaling rates are not increased with depth, the only advantage of using varied advance maintenance in Galveston Channel would be to reduce the new work dredging volume created by the initial advance maintenance dredging. Variation in advance maintenance of 2 and 4 ft between the high and low shoaling sections will be investigated. The project will be grouped into sections 1, 2, 8, 9, and 10 (high shoaling) and sections 3, 4, 5, 6, and 7 (low shoaling). Resulting shoaling patterns with varied advance maintenance are shown in Plate 17b, Plate 18b and c, and Plate 19b and c profiles.

64. The average shoaling rates and required dredging intervals are summarized as follows:

| Advance Maintenance ft | Average Shoaling Rate Thousands of cu yd/yr | Required Dredging Interval, yr |
|---|---|---|
| 3 (existing) | 1,811 | 2.51 |
| 5 | 1,811 | 3.21 |
| 3 and 5 | 1,811 | 3.21 |

(Continued)

| Advance Maintenance ft | Average Shoaling Rate Thousands of cu yd/yr | Required Dredging Interval, yr |
|---|---|---|
| 7 | 1,811 | 3.93 |
| 5 and 7 | 1,811 | 3.93 |
| 3 and 7 | 1,811 | 3.93 |
| 9 | 1,811 | 4.64 |
| 7 and 9 | 1,811 | 4.64 |
| 5 and 9 | 1,811 | 4.64 |

As stated before, advance maintenance does not increase the average shoaling rate for Galveston Channel. Therefore advance maintenance can be used effectively to reduce dredging frequency without any increase in the long-term dredging volume.

Increase in controlling depth while maintaining or reducing dredging frequency

65. The situation is that the existing dredging interval is 2.51 yr, but the controlling depth at section 1 is 34.0 ft rather than the authorized depth of 36 ft. The problem is to increase the controlling depth to 36 ft while maintaining or reducing the dredging frequency. Advance maintenance of 5, 7, and 9 ft along the entire length of the channel as well as varied advance maintenance will be investigated. The shoaling rates and the computational procedures are the same as previously described, except that the controlling depth has been increased from 34.0 to 36 ft. Since the shoaling rates for each section are independent of depth for the depth range under consideration, the average shoaling rate remains unchanged for each scheme evaluated. The only change is that the required dredging interval is reduced compared with the shallower controlling depth. The resulting shoaling patterns for 3, 5, 7, and 9 ft of advance maintenance are shown in Plates 20-23. The average shoaling rate and required dredging intervals are summarized as follows:

| Advance Maintenance ft | Average Shoaling Rate Thousands of cu yd/yr | Required Dredging Interval, yr |
|---|---|---|
| 3 | 1,811 | 1.79 |
| 1 and 3 | 1,811 | 1.79 |
| 5 | 1,811 | 2.50 |
| 3 and 5 | 1,811 | 2.50 |
| 7 | 1,811 | 3.22 |
| 5 and 7 | 1,811 | 3.22 |
| 3 and 7 | 1,811 | 3.22 |
| 9 | 1,811 | 3.94 |
| 7 and 9 | 1,811 | 3.94 |
| 5 and 9 | 1,811 | 3.94 |

For the existing channel maintenance scheme (3 ft of advance maintenance) an attempt to increase the before-dredging controlling depth from the current 34 ft to 36 ft would result in a reduction in the required dredging interval from 2.51 yr to 1.79 yr with no change in the average shoaling rate. To increase the controlling depth while maintaining a required dredging interval of 2.5 yr requires either the 5-ft advance maintenance scheme or the varied advance scheme of 3 and 5 ft. To increase the controlling depth to 36 ft while increasing the required dredging interval beyond the 2.5 yr requires advance maintenance greater than 5 ft.

Hindcast

66. In order to demonstrate the capability of the prediction techniques presented in this report, the dredging requirement (both volume and frequency) for the existing Galveston Channel will be "predicted" using only information from previous conditions. The prediction can then be compared with the actual dredging requirement observed for the existing condition to determine the adequacy of the method in this case.

67. The existing condition (1975) for Galveston Channel is 36 ft deep × 1200 ft wide with 3 ft of advance maintenance. The previous condition was 34 ft deep × 1200 ft wide with 2 ft advance maintenance. Thus, the technique will be employed to "predict" the effect of 3 ft of advance maintenance and the 36-ft-deep channel on dredging requirements.

68. Using Phase 1-Modified analysis from the years 1905 through

1966 (all the available data except for existing condition) results in a regression curve shown in Plate 24, which indicates the shoaling rates for the Galveston Channel as follows:

| Project | Total Depth* | Shoaling Rate Millions of cu yd/yr | Percent Change** |
|---|---|---|---|
| 30 × 1200 | 32 | 1.90 | |
| 32 × 1200 | 34 | 2.03 | 0 |
| 34 × 1200 | 36 | 2.03 | 0 |
| 34 × 1200 | 38 | 2.02 | 0 |

* Includes 2 ft allowable dredging tolerance.
** Compared with immediately previous project.

69. The above results indicate that the increases in the depth of Galveston Channel beyond 34 ft (32-ft project) have not caused increases in the overall project shoaling.

70. Using the Phase 2 analysis for Galveston Channel as discussed in paragraphs 53 and 54 results in the data presented in Table 6 for the 34- and 34-ft (with 2 ft advance maintenance) projects. Based on the tabulation in paragraph 68, it will be projected that increased channel depth by advance maintenance will not increase the average annual maintenance requirement. Thus, it is shown a priori that calculations for 3 ft of advance maintenance will indicate no change in annual dredging volumes.

71. The average dredging interval for the "existing channel" (34 ft project depth with 2 ft advance maintenance), determined from the data in Table 5 (see "Shoaling Interval" column), was 1.98 yr. Based on the shoaling rates from Table 6, the "existing" shoaling pattern at 1.98 yr after dredging indicates a controlling depth of 32.9 ft (in sections 1, 2, and 3).

72. The 3 ft of advance maintenance and 36 ft channel depth will be evaluated with an increased controlling depth from 32.9 to 34 ft (actual observed controlling depth for 3 ft of advance maintenance condition from 1967 through 1975). Three feet of advance maintenance

and 36 ft channel depth increases the after-dredging depth from 38 to 41 ft. The first sections that require evaluation are the controlling sections 1, 2, and 3. Since the after-dredging depth is 41 ft and the shoaling rate for sections 1, 2, and 3 is 2.6 ft/yr, the section will shoal from 41 to 34 ft in 2.69 yr.

73. The average shoaling rates and required dredging intervals are summarized as follows:

| Project Description Advance Maintenance ft | Controlling Depth ft | Shoaling Rate Thousands of cu yd/yr | Dredging Interval yr |
|---|---|---|---|
| 34 ft project depth with 2 ft advance maintenance ("existing") | 32.9 | 2,020 | 1.98 |
| 36 ft project depth with 3 ft advance maintenance | | | |
| (predicted) | 34.0 | 2,020 | 2.69 |
| (observed) | 34.0 | 1,780 | 2.51 |

74. As can be seen, good agreement is achieved for the predicted required dredging interval with 3 ft of advance maintenance and 34 ft controlling depth (2.69 yr) and the observed required dredging interval (2.51 yr). The predicted shoaling rate was left unchanged from previous conditions at 2020 thousand cu yd/yr while the observed shoaling ra[illegible] decreased slightly to 1780 thousand cu yd/yr. The hindcast is thus completed with the conclusion that the prediction scheme was satisfactory for both dredging volume and frequency in this case.

## Texas City Channel

75. The Texas City Channel, located in the western part of lower Galveston Bay (Figure 11), was originally authorized by Congress in 1899 at dimensions of 25 ft × 100 ft. Natural depths varied from 4 to 8 ft. In 1915 and 1916, the channel was deepened and widened to 30 ft × 300 ft. In 1931 the turning basin was enlarged from 600- to 800-ft width. The change in turning basin dimensions was not considered

significant enough to prohibit comparison of pre-1931 project dredging data and post-1931 project dredging data. In 1937, the channel was deepened so that the dimensions were 34 ft × 300 ft. During 1959 and 1960, the channel was again deepened and widened to 36 ft × 400 ft. In 1966 and 1967, the channel was again deepened, resulting in the existing dimensions of 40 ft × 400 ft over a distance of 6.75 miles. The pre- and postdredge survey sheets for the Texas City Channel from 1962 to 1975, obtained from the Galveston District, indicated that from 1961 to 1965 the contract dredging depths were 36 ft plus 2 ft advance maintenance plus 2 ft allowable dredging tolerance; from 1965 to 1966 the depths were 36 ft plus 3 ft advance maintenance plus 2 ft allowable dredging tolerance; and from 1966 through 1975, the depths were 40 ft plus 3 ft advance maintenance plus 2 ft allowable dredging tolerance. These design depths and the actual average postdredge depths for the periods from 1962 to 1975 are shown in Plate 25.

Phase 1

76. Using the procedures described in PART II for Phase 1 analysis, the annual report dredging data for the Texas City Channel are tabulated in Table 7 and graphically displayed in Plate 26 as maintenance dredging and new work volume versus fiscal year. The second data plot, annual maintenance dredging versus accumulated new work, is presented in Plate 27. The regression curve indicates required dredging volumes as follows:

| Project | Total Depth* ft | Maintenance Dredging Volumes Millions of cu yd/yr | Percent Change** |
|---|---|---|---|
| 25 ft × 100 ft | 27 | 0.40 | -- |
| 30 ft × 300 ft | 32 | 0.95 | +138 |
| 30 ft × 300 ft† | 32 | 1.05 | +11 |
| 34 ft × 300 ft | 36 | 1.14 | +7 |
| 36 ft × 400 ft | 40 | 1.35 | +18 |
| 40 ft × 400 ft | 45 | 1.47 | +9 |

* Includes allowable dredging tolerance and advance maintenance.
** Compared with immediately previous project.
† Enlarged turning basin.

Phase 1-Modified

77. The preceding analysis was based only on fiscal year dredging volumes from the Corps Annual Reports. Since the dates of dredging activity for the Texas City Channel are also provided in the Annual Reports, the analysis can be refined to increase its predictive capability by computing shoaling rates based on dredging volumes and actual time intervals rather than intervals restricted to whole years as was the case for Phase 1. The average shoaling rates based on dredging volumes for each shoaling interval are shown in Table 8. The shoaling histogram as described in paragraphs 18 and 19 in PART II results in the regression curve shown in Plate 28, which indicates overall shoaling rates as follows:

| Project | Total Depth* ft | Shoaling Rate Millions of cu yd/yr | Percent Change** |
|---|---|---|---|
| 25 × 100 | 27 | 0.42 | |
| 30 × 300 | 32 | 0.99 | +136 |
| 30 × 300† | 32 | 1.10 | +11 |
| 34 × 300 | 36 | 1.20 | +9 |
| 36 × 400 | 40 | 1.44 | +20 |
| 40 × 400 | 45 | 1.60 | +11 |

* Includes allowable dredging tolerance and advance maintenance.
** Compared with immediately previous project.
† Enlarged turning basin.

Phase 2

78. Hydrographic survey data were available from the Galveston District from 1960 through 1975. Phase 2 results will be compared with the results obtained by Phases 1 and 1-Modified and will be used to determine shoaling rates along the Texas City Channel.

79. The survey data associated with the dredging activity occurring during November 1961-February 1962; May-June 1963; January-May 1965; May-August 1966; March-May 1968; February-April 1970; May-July 1972; and August 1974-January 1975 were available from the Galveston District. Using these survey data, the project was segmented into nine sections

(Figure 14), and the section shoaling rate for each of the shoaling periods was computed as shown in Table 9. Project shoaling for the three periods with the 36-ft authorized depth with 2 to 3 ft advance maintenance and 2 ft allowable dredging tolerance averaged 1.53 million cu yd/yr. Project shoaling for the four shoaling periods with an authorized depth of 40 ft with 3 ft advance maintenance and 2 ft allowable overdepth averaged 1.65 million cu yd/yr.

80. The average dredging interval for the existing channel, determined from the data in Table 8 (see "Shoaling Interval" column), was 1.89 yr. Based on the shoaling rates from Table 9, the existing shoaling pattern at 1.89 yr after dredging is shown in Figure 15, indicating a controlling depth of 36.7 ft (in section 8).

Shoaling predictions

81. The controlling depth, which occurs in section 8, is assumed to be 36.7 ft to agree with the shoaling pattern in Figure 15. Increased advance maintenance can be applied either to reduce the dredging frequency and maintain the 36.7-ft controlling depth in section 8 or to increase the controlling depth to 40.0 ft (authorized) while maintaining or reducing the dredging frequency. A summary of Phases 1, 1-Modified, and 2 results is as follows:

| Phase | Shoaling in Thousands of cu yd/yr | | | | | |
|---|---|---|---|---|---|---|
| | 25 × 100 ft | 30 × 300 ft | 30 × 300 ft (enlarged TB) | 34 × 300 ft | 36 × 400 ft | 40 × 400 ft |
| 1 | 400 | 950 | 1,050 | 1,140 | 1,350 | 1,470 |
| 1-Mod | 420 | 990 | 1,100 | 1,200 | 1,440 | 1,600 |
| 2 | -- | -- | -- | -- | 1,533 | 1,640 |

82. Comparison of Phase 2 with Phase 1-Modified indicates that Phase 1-Modified is a reasonable estimation of the historical shoaling rates in the Texas City Channel.

83. The increase in the shoaling rate for the 4-ft increment from 36 to 40 ft (from 20,340 to 26,510 thousand cu yd accumulated new work) indicated by the Phase 1-Modified curve is 11 percent. The curve also indicates a decreasing rate of increase with depth. For the following

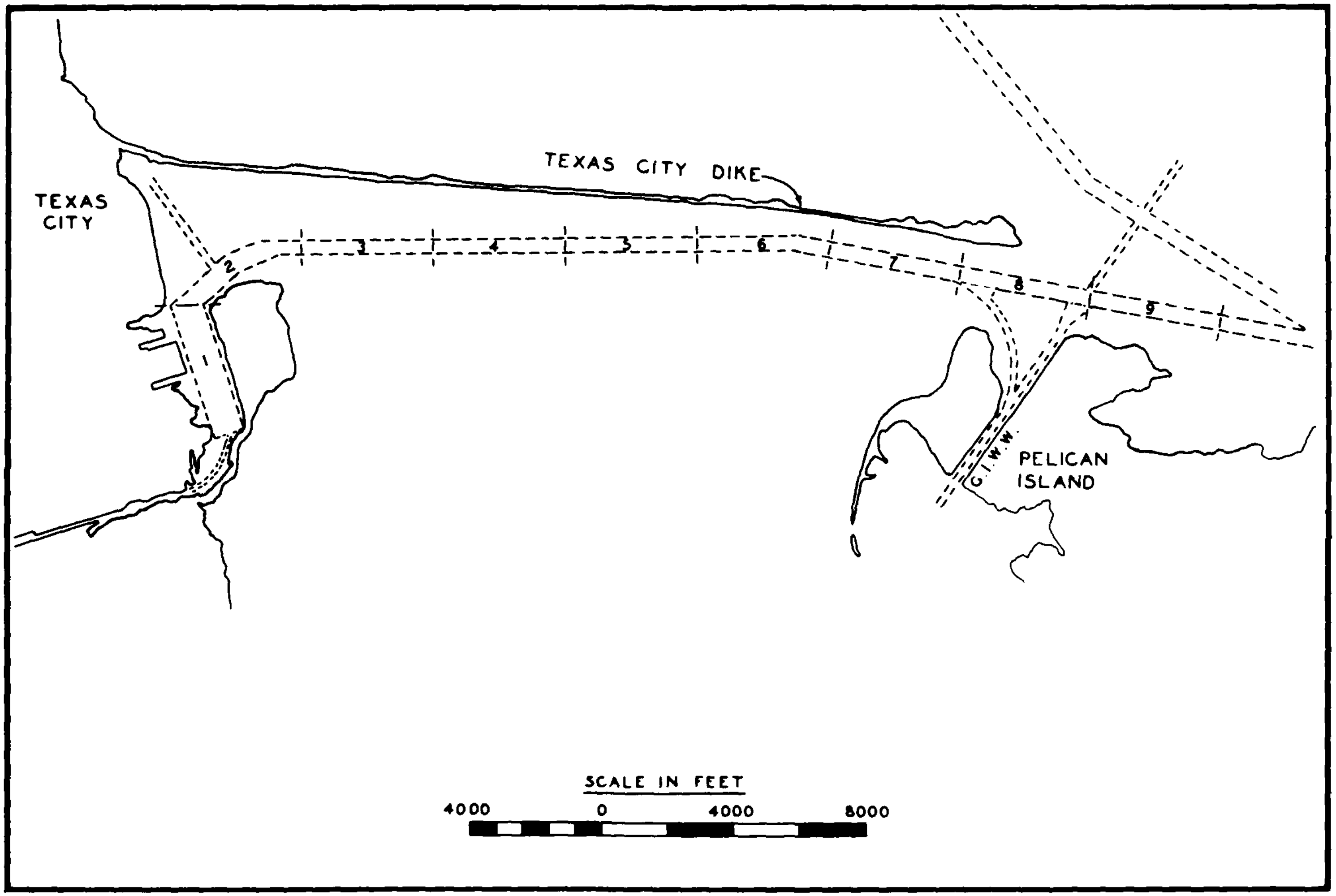



Figure 14. Texas City Channel location map

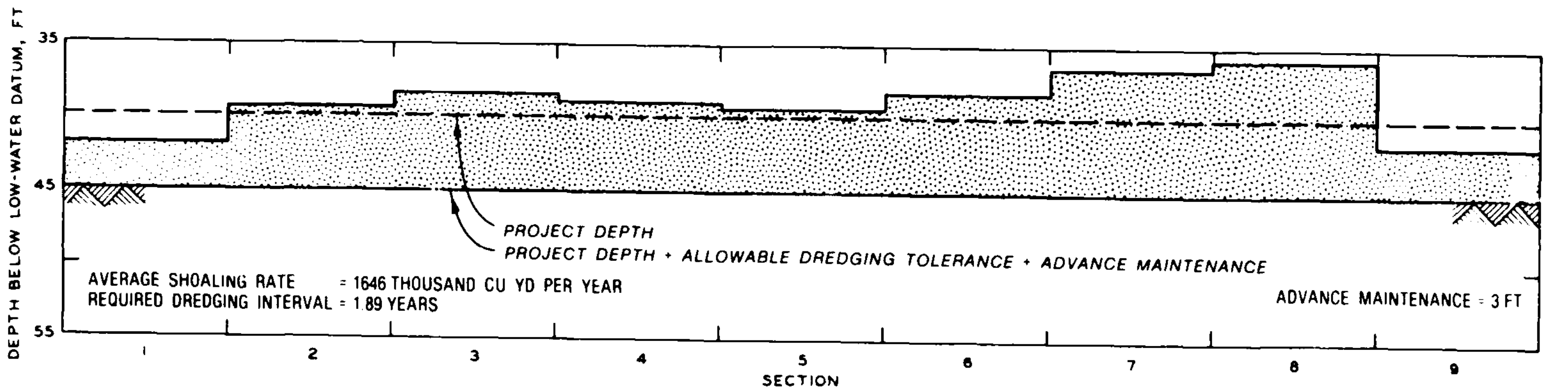



Figure 15. Texas City Channel existing shoaling pattern

evaluation of dredging tolerances, the increase in shoaling will be held constant at 5 percent (per 2-ft increment) rather than decreased.

84. Using the 5 percent rate of increase from 3 to 9 ft of advance maintenance, the shoaling rates for the nine sections (rounded to the nearest tenth of a foot per year) are:

| | Predicted Shoaling Rates, ft/yr, for Sections | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Depth, ft | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Less than 45* | 1.5 | 2.7 | 3.2 | 2.9 | 2.7 | 3.2 | 4.1 | 4.4 | 1.6 |
| 45 to 47 | 1.6 | 2.8 | 3.4 | 3.0 | 2.8 | 3.4 | 4.3 | 4.6 | 1.7 |
| 47 to 49 | 1.7 | 2.9 | 3.6 | 3.2 | 2.9 | 3.6 | 4.5 | 4.8 | 1.8 |
| 49 to 51 | 1.8 | 3.0 | 3.8 | 3.4 | 3.0 | 3.8 | 4.7 | 5.0 | 1.9 |

* These shoaling rates are taken directly from Table 9.

The above incremental shoaling rates will be applied to all advance maintenance dredging predictions for the Texas City Channel.

Reduction in dredging frequency while maintaining controlling depth

85. Increased advance maintenance of 5, 7, and 9 ft was evaluated along with varied advance maintenance using the procedure described in PART II for the example channel. Resulting shoaling patterns are shown in Plates 29-31. For varied advance maintenance, the high shoaling rate sections were considered to be sections 7 and 8; and the low shoaling rate sections were considered to be sections 1, 2, 3, 4, 5, 6, and 9. The average shoaling rates and required dredging intervals for each of the advance maintenance schemes investigated are summarized as follows:

| Advance Maintenance ft | Average Shoaling Rate Thousands of cu yd/yr | Required Dredging Interval, yr |
|---|---|---|
| 3 (existing) | 1,646 | 1.89 |
| 5 | 1,677 | 2.32 |
| 3 and 5 | 1,655 | 2.32 |
| 7 | 1,712 | 2.74 |
| 5 and 7 | 1,681 | 2.74 |
| 3 and 7 | 1,663 | 2.74 |

(Continued)

| Advance Maintenance ft | Average Shoaling Rate Thousands of cu yd/yr | Required Dredging Interval, yr |
|---|---|---|
| 9 | 1,756 | 3.14 |
| 7 and 9 | 1,715 | 3.14 |
| 5 and 9 | 1,667 | 3.14 |

86. As can be seen, for a given dredging interval the application of varied advance maintenance can result in a slight reduction in the dredging volume compared with the same depth of advance maintenance applied uniformly to the channel. Figure 16 presents the shoaling rate-dredging interval curve using the most efficient of the combinations of advance maintenance evaluated. This curve would be used for any subsequent economic analysis to determine the applicability of advance maintenance.

Increase in controlling depth while maintaining or reducing dredging frequency

87. Increased advance maintenance of 5, 7, and 9 ft was evaluated along with varied advance maintenance using the procedure described in PART II for the example. Resulting shoaling patterns are shown in Plates 32-35. For varied advance maintenance the high shoaling rate sections were again considered to be sections 7 and 8, and the low shoaling rate sections were considered to be sections 1, 2, 3, 4, 5, 6, and 9. The average shoaling rates and required dredging intervals for each of the advance maintenance schemes investigated are summarized as follows:

| Advance Maintenance ft | Average Shoaling Rate Thousands of cu yd/yr | Required Dredging Interval, yr |
|---|---|---|
| 3 | 1,646 | 1.14 |
| 5 | 1,689 | 1.57 |
| 3 and 5 | 1,654 | 1.57 |
| 7 | 1,735 | 1.99 |
| 5 and 7 | 1,692 | 1.99 |
| 9 | 1,785 | 2.39 |
| 7 and 9 | 1,736 | 2.39 |
| 5 and 9 | 1,697 | 2.39 |

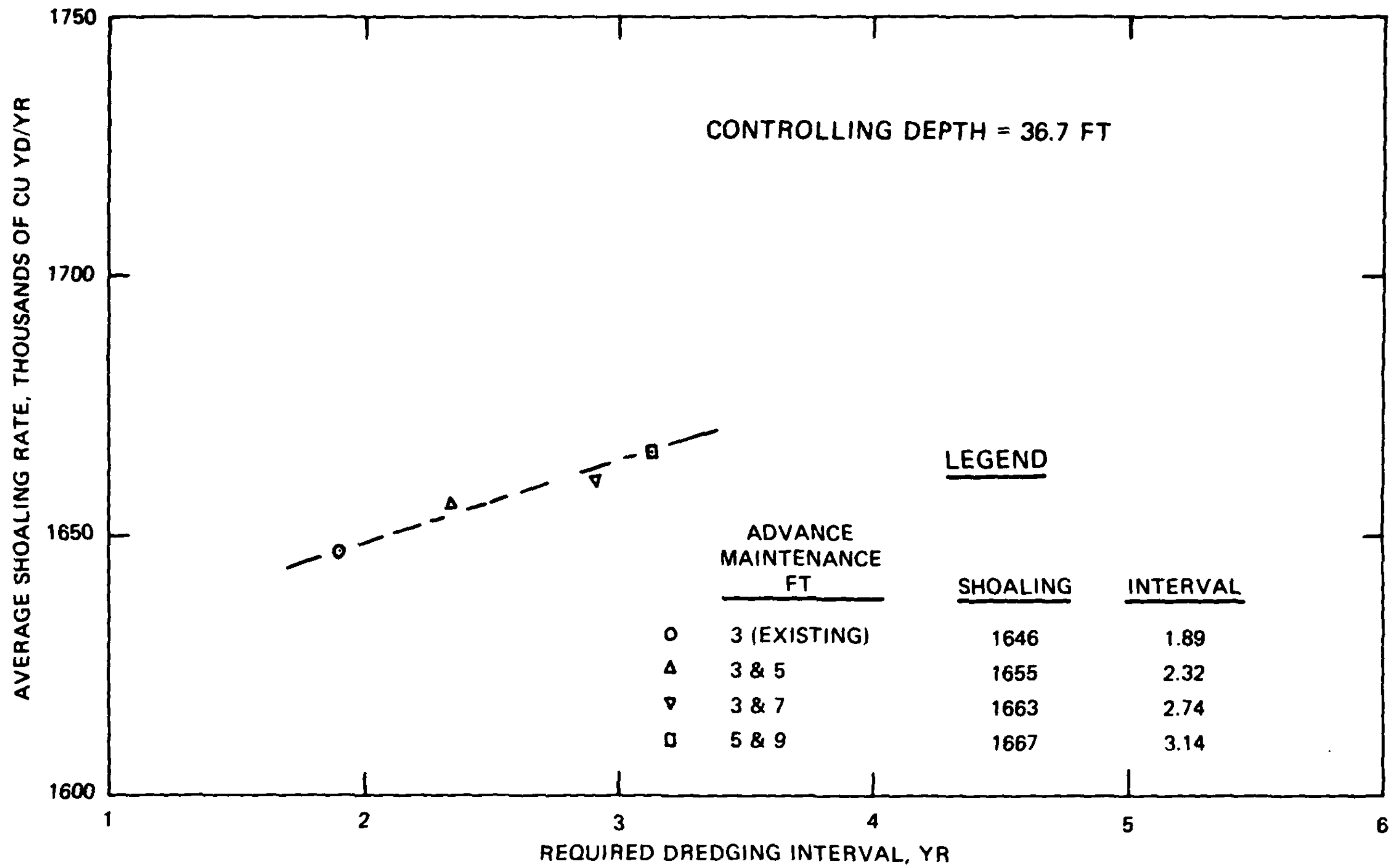



Figure 16. Texas City Channel dredging interval-shoaling relation for various schemes of advance maintenance with a controlling depth of 36.7 *ft*

88. As can be seen, for a given dredging interval the application of varied advance maintenance can result in a slight reduction in the dredging volume compared with the same depth of advance maintenance applied uniformly to the channel. Figure 17 presents the shoaling rate-dredging interval curve using the most efficient of the combinations of advance maintenance evaluated. This curve would be used for any subsequent economic analysis to determine the applicability of advance maintenance.

Hindcast

89. As was done for Galveston Channel, the dredging requirement (both volume and frequency) for the existing Texas City Channel will be "predicted" using only information from previous conditions. The prediction can then be compared with the actual dredging requirement observed for the existing condition to determine the adequacy of the method in this case.

90. The existing condition for Texas City Channel is 40 ft deep at mlw by 400 ft wide with 3 ft of advance maintenance. The previous condition was 36 ft deep at mlw by 400 ft wide with 2 ft of advance maintenance. Thus, the technique will be employed to "predict" the combined effect of channel deepening (36 to 40 ft) and increased advance maintenance (2 to 3 ft) on the project dredging requirements.

91. Using Phase 1-Modified analysis from the years 1906 through 1967 (all the available data except existing conditions) results in a regression curve shown in Plate 36, which indicates the overall shoaling rates for the Texas City Project as follows:

| Project | Total Depth* ft | Shoaling Rate Millions of cu yd/yr | Percent Change** |
|---|---|---|---|
| 25 × 100 | 27 | 0.44 | |
| 30 × 300 | 32 | 1.01 | +139 |
| 30 × 300† | 32 | 1.12 | +11 |
| 34 × 300 | 36 | 1.20 | +7 |
| 36 × 300 | 40 | 1.37 | +14 |

* Includes allowable dredging tolerance and advance maintenance.

** Percent change from immediately previous project.

† Enlarged turning basin.

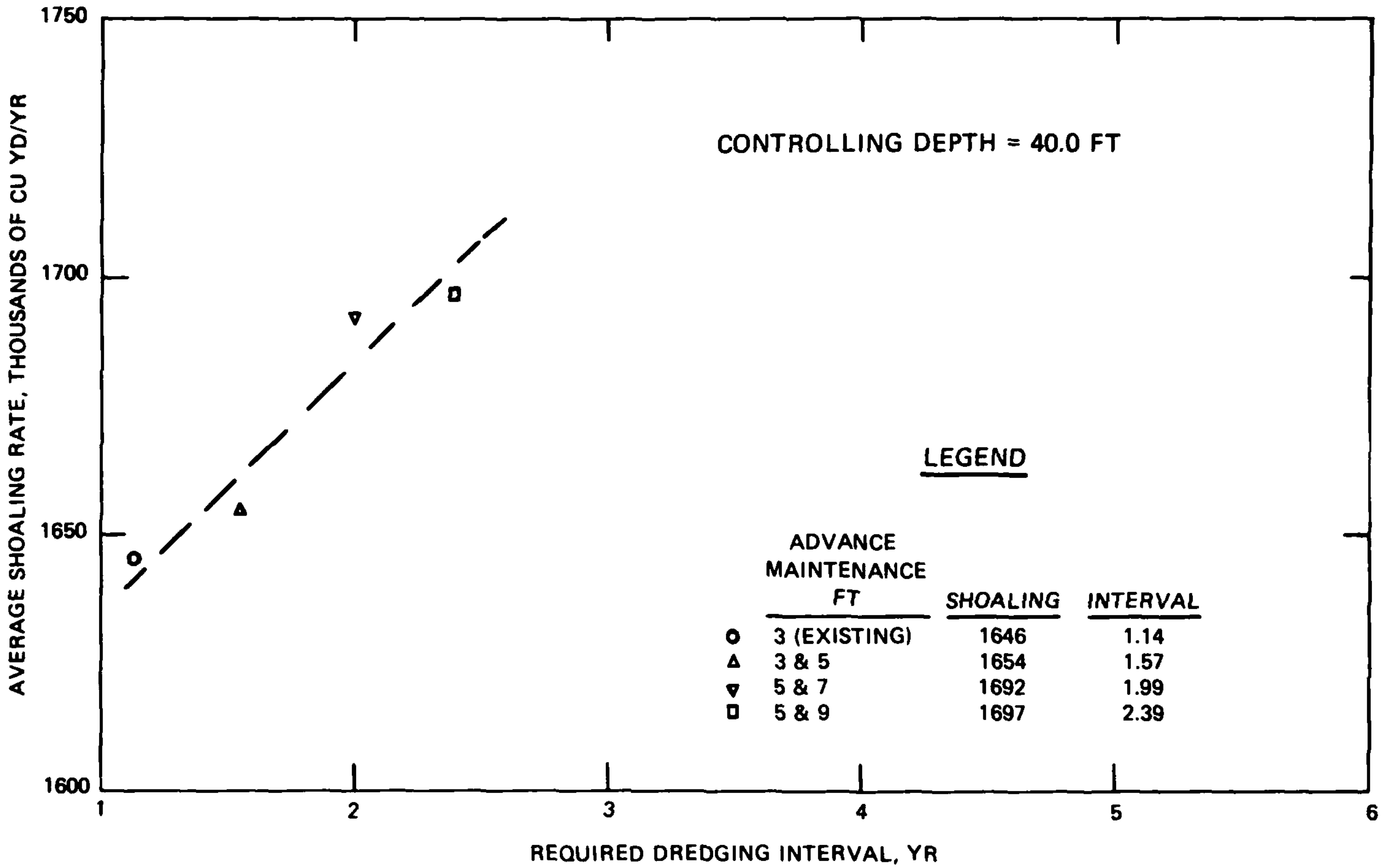



Figure 17. Texas City Channel dredging interval-shoaling relation for various schemes of advance maintenance with a controlling depth of 40 ft

92. The first step for the analysis is to estimate the shoaling rate for a 40-ft project by extrapolating the regression curve presented in Plate 36. Before the extrapolation can be made, however, the 40-ft depth condition must be converted to its equivalent new work dredging required to achieve the 40-ft depth condition. The estimated new work dredging to deepen the channel from 36- to 40-ft project depth is about 2.37 million cu yd for the channel bottom, based on 4-ft increase in depth times 400-ft width times 32,000-ft length (channel section) plus 4-ft increase in depth times 800-ft width times 4000-ft length (harbor section). Additionally, the estimated new work dredging along the channel side slopes (1 on 2) is roughly about 1.00 million cu yd. The total new work dredging to enlarge the project from 36- to 40-ft depth is roughly estimated at 3.37 million cu yd. Extrapolation of the regression curve presented in Plate 36 (equational form of $y = -0.00182X^2 + 0.10410X$) to include the additional 3.37 million cu yd estimated new work dredging results in a shoaling rate for the 40-ft depth project of 1.48 million cu yd/yr, or an increase of about 8 percent from the 36-ft channel. The increase of 8 percent for the 4-ft depth increment (2 percent per foot of depth) will be used to establish a shoaling rate-depth relation for the advance maintenance condition.

93. Using the Phase 2 analysis for the Texas City project as discussed in paragraphs 77 through 79 results in the data presented in Table 9 for the 36-ft project.

94. The average dredging interval for the "existing channel" (36-ft project depth) determined from the data in Table 8 (see "Shoaling Interval" column) was 1.79 yr. Based on the shoaling rates from Table 9, the "existing" shoaling pattern of 1.79 yr indicates a controlling depth of 32.8 ft in section 8, or 3.2 ft less than project depth of 36 ft at mlw. The 3 ft of advance maintenance for the 40-ft project will be evaluated to reduce dredging frequency while maintaining the 36.7-ft controlling depth (observed) in section 8.

95. The predicted shoaling rates (based on the 2 percent increase per foot of depth in the range of consideration) for the nine sections shown in Figure 14 are:

| | Predicted Shoaling Rates, ft/yr, for Sections | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Less than 40* | 2.5 | 2.4 | 3.0 | 2.2 | 2.5 | 2.4 | 3.3 | 4.0 | 1.2 |
| 40 to 41 | 2.6 | 2.4 | 3.1 | 2.2 | 2.6 | 2.4 | 3.4 | 4.1 | 1.2 |
| 41 to 42 | 2.6 | 2.5 | 3.1 | 2.3 | 2.6 | 2.5 | 3.4 | 4.2 | 1.3 |
| 42 to 43 | 2.7 | 2.5 | 3.2 | 2.3 | 2.7 | 2.5 | 3.5 | 4.2 | 1.3 |
| 43 to 44 | 2.7 | 2.6 | 3.2 | 2.4 | 2.7 | 2.6 | 3.6 | 4.3 | 1.3 |
| 44 to 45 | 2.8 | 2.7 | 3.3 | 2.4 | 2.8 | 2.7 | 3.6 | 4.4 | 1.3 |

* These shoaling rates are taken directly from Table 9.

96. Using the above predicted shoaling rates and the procedure described in PART II for the example channel results in average shoaling rates and required dredging intervals as follows:

| Project Depth ft | Advanced Maintenance ft | Controlling Depth ft | Average Shoaling Rate Thousands of cu yd/yr | Required Dredging Interval yr |
|---|---|---|---|---|
| 36 ("existing") | 2 | 32.9 | 1,370 | 1.79 |
| 40 (predicted) | 3 | 36.7 | 1,480 | 2.01 |
| 40 (observed) | 3 | 36.7 | 1,600 | 1.89 |

97. As can be seen, satisfactory agreement is achieved for the predicted required dredging interval (2.01 yr) and the observed required dredging interval (1.89 yr). It must be realized that the effect of channel deepening alone would be to reduce the dredging interval while the effect of increased advance maintenance would be to increase the dredging interval. The fact that the prediction scheme not only correctly indicated that the combined effect would cause an increase in the dredging interval, but also predicted the amount of increase in dredging interval reasonably well is encouraging. Good agreement was also achieved with regard to the average shoaling rate, with the prediction being slightly less than that observed (1.48 million cu yd/yr predicted versus 1.60 million cu yd/yr observed). Thus, the hindcast is completed with the conclusion that the prediction scheme performed satisfactorily in this case.

## Houston Ship Channel

98. The existing project (Figure 11) was originally authorized by the Act of 5 March 1905 and modified by subsequent acts. In 1919, a 30-ft-deep channel was authorized. In 1935, authorization was given to deepen the channel to 32 ft and widen the channel through Galveston Bay to 400 ft. In 1935, authorization was given to further deepen the channel to 34 ft. In 1948, authorization was given to further deepen the channel to 36 ft. The existing authorization was given by Congress in 1958. It now provides for a channel 40 ft deep and 400 ft wide extending about 26 miles across Galveston Bay from Bolivar Roads, just within the entrance to Galveston Bay, and into Buffalo Bayou an additional distance of a little under 21 miles; thence, the project dimensions of the channel within Buffalo Bayou are 40 ft deep × 300 ft wide for a distance of a little less than 1 mile and 36 ft × 300 ft for an additional distance of about 3 miles to a turning basin 36 ft deep and having a width varying from 400 to 1000 ft. Since about 48 miles of the 51-mile-long channel are maintained at 40-ft depth, the project will hereafter be referred to as the 40-ft depth project. The total length of the channel described including the turning basin is approximately 51 miles. Present dredging procedure includes 2 ft of advance maintenance and 2 ft allowable dredging tolerance.

### Phase 1

99. Since the Annual Report dredging data for the Houston Ship Channel lists dredging below Morgan Point (Galveston Bay section) separately from the dredging above Morgan Point (Buffalo Bayou section), Phase 1 analysis will be applied independently to the Galveston Bay section and to the Buffalo Bayou section.

100. The Annual Report dredging data for the Galveston Bay section and the Buffalo Bayou section are presented in Tables 10 and 11 and graphically displayed in Plates 37 and 38 as maintenance and new work dredging volume versus fiscal year. The annual maintenance versus accumulated new work (channel dimensions) graphs are presented in Plates 39 and 40. Regression curves, fitted to the data, serve as

guidelines for the shoaling behavior as a function of channel dimensions. The regression curves indicate the required dredging volumes as follows:

| Project Dimensions ft | Total Depth* ft | Required Dredging Thousands of cu yd/yr | Percent Change** |
|---|---|---|---|
| | | Galveston Bay Section | |
| 25 × 100 | 27 | 1,833 | -- |
| 30 × 250 | 32 | 2,320 | +27 |
| 34 × 400 | 36 | 2,357 | +2 |
| 36 × 400 | 38 | 2,210 | -6 |
| 40 × 400 | 44 | 1,923 | -13 |
| | | Buffalo Bayou Section | |
| 25 × 100 | 27 | 987 | -- |
| 30 × 250 | 32 | 1,597 | +62 |
| 32 × 400 | 34 | 2,049 | +28 |
| 36 × 400 | 38 | 2,205 | +8 |
| 40 × 400 | 44 | 2,071 | -6 |

* Includes allowable dredging tolerance and advance maintenance.
** Compared with immediately previous project.

The above results indicate that after the more recent increases in project depth the overall shoaling volumes actually slightly decreased.

Phase 1-Modified

101. The preceding analysis was based only on fiscal year dredging volumes from the Corps Annual Reports. Since, for the Houston Ship Channel, the dates of dredging activity are also provided in the Annual Reports, an analysis can be made by computing shoaling rates based on dredging volumes for each shoaling interval shown in Tables 12 and 13. Using the procedure described in paragraphs 18 and 19 in PART II results in the regression curve shown in Plates 41 and 42, which shows the shoaling rates for the Houston Ship Channel as follows:

| Project Dimensions ft | Total Depth* ft | Required Dredging Thousands of cu yd/yr | Percent Change** |
|---|---|---|---|
| | | Galveston Bay Section | |
| 25 × 100 | 27 | 1,926 | -- |
| 30 × 250 | 32 | 2,508 | +30 |
| 34 × 400 | 36 | 2,672 | +7 |
| 36 × 400 | 38 | 2,596 | -3 |
| 40 × 400 | 44 | 2,397 | -8 |
| | | Buffalo Bayou Section | |
| 25 × 100 | 27 | 847 | -- |
| 30 × 250 | 32 | 1,367 | +61 |
| 32 × 400 | 34 | 1,751 | +28 |
| 36 × 400 | 38 | 1,879 | +7 |
| 40 × 400 | 44 | 1,751 | -7 |

* Includes allowable dredging tolerance and advance maintenance.

** Compared with immediately previous project.

The above results, as was the case for the Phase 1 analysis, indicate that after the more recent increases in project depth, the overall project shoaling has slightly decreased.

102. Phase 2 analysis was not applied to the Houston Ship Channel because of the unavailability of adequate hydrographic survey data. However, based on the results from Phase 1 and 1-Modified, increased overdepth dredging beyond the current 2 ft probably would not cause any significant change in overall shoaling.

## PART IV: CONCLUSION

103. Before a prediction of future dredging requirements for a proposed deepened or an advance-maintained channel can be attempted, a determination of the effect of depth on shoaling must be made. This report presented an empirical method, based on historical dredging and shoaling data, which provides a rational approach to the problem.

104. The approach included several simplifying assumptions, listed in paragraph 11. Before any project is evaluated as described in this report, it should be first determined that the assumptions made will not severely affect the results. If it is determined that an assumption is not valid for the project to be investigated, the procedure should be modified to avoid the offending assumption.

105. The method of shoaling analysis was described using an example project. The procedure basically involved two steps. The first step was to determine the effect of past changes in depth on shoaling. The second step was to extrapolate the shoaling-depth relation to the proposed advance maintenance or deepened condition to determine required dredging frequencies and volumes. The method was then applied to selected projects in Galveston Bay - Galveston Channel, Texas City Channel, and Houston Ship Channel. The purpose was to demonstrate how the procedure can be applied to real projects. Hindcasts performed on the Galveston and Texas City projects indicated that the technique gave satisfactory predictions for both dredging volumes and frequencies in these two cases. Problems can occur when dealing with real projects when reported dredging volumes are not in reasonable agreement with the observed shoaling volumes for the period investigated. Additional research is then required to determine the adequacy of available data before a predictive technique to define shoaling as a function of depth could be considered reliable.

106. In summary, the approach presented in this report requires considerably more effort than the arbitrary, rule-of-thumb procedures predictors described in paragraph 5; but the result should be a much more reliable prediction of the effect of advance maintenance dredging or

channel deepening on a dredged navigation project.

107. As these procedures may be applied to a navigation channel, each new set of data should be used to update the predictions on the effectiveness of advanced maintenance.

Table 1

Dredging History of Example Channel, Millions of Cubic Yards

| Fiscal Year | Annual New Work | Accumulated New Work | Annual Maintenance |
|---|---|---|---|
| 1930 | 1.520 | 0. | 0. |
| 1931 | 1.570 | 1.520 | 0. |
| 1932 | 0.470 | 3.090 | 0.520 |
| 1933 | 0. | 3.560 | 0. |
| 1934 | 0. | 3.560 | 1.270 |
| 1935 | 0. | 3.560 | 0. |
| 1936 | 0. | 3.560 | 0. |
| 1937 | 0. | 3.560 | 0.870 |
| 1938 | 0. | 3.560 | 0. |
| 1939 | 0. | 3.560 | 0.920 |
| 1940 | 0. | 3.560 | 0. |
| 1941 | 0. | 3.560 | 0. |
| 1942 | 0. | 3.560 | 0. |
| 1943 | 1.350 | 3.560 | 1.420 |
| 1944 | 0. | 4.910 | 0.370 |
| 1945 | 0. | 4.910 | 0. |
| 1946 | 0. | 4.910 | 0.760 |
| 1947 | 0. | 4.910 | 0. |
| 1948 | 0. | 4.910 | 1.020 |
| 1949 | 0. | 4.910 | 0. |
| 1950 | 0. | 4.910 | 0.170 |
| 1951 | 0. | 4.910 | 0.790 |
| 1952 | 0. | 4.910 | 0. |
| 1953 | 0. | 4.910 | 0. |
| 1954 | 0. | 4.910 | 1.090 |
| 1955 | 0. | 4.910 | 0.310 |
| 1956 | 0. | 4.910 | 0. |
| 1957 | 0. | 4.910 | 0. |
| 1958 | 0. | 4.910 | 0. |
| 1959 | 0. | 4.910 | 1.400 |
| 1960 | 3.030 | 4.910 | 0.240 |
| 1961 | 1.240 | 7.940 | 0.080 |
| 1962 | 0. | 9.180 | 0. |
| 1963 | 0. | 9.180 | 2.030 |
| 1964 | 0. | 9.180 | 0. |
| 1965 | 0. | 9.180 | 0.740 |
| 1966 | 0. | 9.180 | 1.090 |
| 1967 | 1.890 | 9.180 | 0.350 |
| 1968 | 0. | 11.070 | 0. |
| 1969 | 0. | 11.070 | 1.140 |
| 1970 | 0. | 11.070 | 0. |
| 1971 | 0. | 11.070 | 0. |
| 1972 | 0. | 11.070 | 1.320 |
| 1973 | 0. | 11.070 | 0. |
| 1974 | 0. | 11.070 | 0. |
| 1975 | 0. | 11.070 | 2.810 |

Note: Data taken from CE Annual Reports.

Table 2

Example Channel Shoaling Rates Computed from Dredging Volumes

| Channel Dimensions ft | Accumulated New Work* | Maintenance Dredging | | | | Shoaling Interval | | | Computed Shoaling Rate* | Computed Average Shoaling Rate* |
|---|---|---|---|---|---|---|---|---|---|---|
| | | FY | From | To | Volume* | From | To | Years | | |
| Pre 30 × 300 | 3,090 | 1932 | 2 Dec 31 | 4 Mar 32 | 520 | 1 Jul 31 | 4 Mar 32 | 0.68 | 768 | 768 |
| 30 × 300 | 3,560 | 1932-34 | 13 Feb 34 | 5 Jun 34 | 1,270 | 5 Mar 32 | 5 Jun 34 | 2.25 | 563 | |
| | | 1934-37 | 1 Sep 36 | 7 Jan 37 | 870 | 6 Jun 34 | 7 Jan 37 | 2.59 | 336 | |
| | | 1937-39 | 1 Jul 38 | 23 Oct 38 | 920 | 8 Jan 37 | 23 Oct 38 | 1.79 | 513 | |
| | | 1939-44 | 7 Apr 43 | 9 Aug 43 | 1,790 | 24 Oct 38 | 9 Aug 43 | 4.79 | 373 | 424 |
| 32 × 300 | 4,910 | 1944-46 | 15 Jan 46 | 4 May 46 | 760 | 10 Aug 43 | 4 May 46 | 2.73 | 278 | |
| | | 1946-48 | 18 Aug 47 | 29 Dec 47 | 1,020 | 5 May 46 | 29 Dec 47 | 1.65 | 616 | |
| | | 1948-51 | 25 May 50 | 14 Sep 50 | 960 | 30 Dec 47 | 14 Sep 50 | 2.75 | 349 | |
| | | 1951-55 | 2 Feb 54 | 10 Aug 54 | 1,400 | 15 Sep 50 | 10 Aug 54 | 3.86 | 363 | |
| | | 1955-60 | 24 Mar 59 | 29 Jul 59 | 1,640 | 11 Aug 54 | 29 Jul 59 | 4.97 | 330 | |
| | | 1960-61 | 13 Feb 61 | 2 Mar 61 | 80 | 30 Jul 59 | 2 Mar 61 | 1.59 | 50 | 334 |
| 34 × 400 | 9,180 | 1961-63 | 12 Nov 62 | 5 Feb 63 | 2,030 | 3 Mar 61 | 5 Feb 63 | 1.93 | 1,051 | |
| | | 1963-66 | 12 May 65 | 15 Oct 65 | 1,830 | 6 Feb 63 | 15 Oct 65 | 2.69 | 680 | |
| | | 1966-67 | 20 Feb 67 | 15 May 67 | 350 | 16 Oct 65 | 15 May 67 | 0.58 | 610 | 810 |
| 36 × 400 | 11,070 | 1967-69 | 8 Aug 68 | 29 Nov 68 | 1,140 | 16 May 67 | 29 Nov 68 | 1.04 | 1,096 | |
| | | 1969-72 | 1 Feb 72 | 18 May 72 | 1,320 | 30 Nov 68 | 18 May 72 | 3.47 | 381 | |
| | | 1972-75 | 13 Aug 74 | 24 Nov 74 | 2,810 | 19 May 72 | 24 Nov 74 | 2.52 | 1,115 | 750 |

Note: Dredging volumes are similar to data available in CE Annual Reports; dates of surveys may be in CE Annual Reports or in district files.

* In thousands of cubic yards.

Table 3

Example Channel Shoaling

Thousands of Cubic Yards per Year and in Feet per Year

| | 34- × 400-ft Channel | | | | | | | | 36- × 400-ft Channel | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mar 61 to Oct 62 | | Feb 63 to Mar 65 | | Nov 65 to Jan 67 | | Avg | | Jun 67 to Jul 68 | | Dec 68 to Dec 71 | | Jun 72 to Jul 74 | | Avg | |
| Channel Section | thou cu yd | ft/yr | thou cu yd | ft/yr | thou cu yd | ft/yr | thou cu yd | ft/yr | thou cu yd | ft/yr | thou cu yd | ft/yr | thou cu yd | ft/yr | thou cu yd | ft/yr |
| 1 | 41 | 0.5 | 47 | 0.6 | 34 | 0.4 | 41 | 0.5 | 35 | 0.4 | 45 | 0.6 | 39 | 0.5 | 40 | 0.5 |
| 2 | 62 | 0.8 | 58 | 0.7 | 71 | 0.9 | 64 | 0.8 | 57 | 0.7 | 51 | 0.7 | 62 | 0.8 | 57 | 0.7 |
| 3 | 59 | 0.8 | 67 | 0.9 | 70 | 0.9 | 65 | 0.8 | 58 | 0.7 | 65 | 0.8 | 63 | 0.8 | 62 | 0.8 |
| 4 | 53 | 0.7 | 61 | 0.8 | 75 | 1.0 | 63 | 0.8 | 64 | 0.8 | 72 | 0.9 | 81 | 1.0 | 72 | 0.9 |
| 5 | 98 | 1.3 | 89 | 1.1 | 102 | 1.5 | 97 | 1.2 | 95 | 1.2 | 84 | 1.1 | 102 | 1.3 | 94 | 1.2 |
| 6 | 87 | 1.1 | 94 | 1.2 | 95 | 1.2 | 92 | 1.2 | 124 | 1.6 | 110 | 1.4 | 131 | 1.7 | 122 | 1.6 |
| 7 | 71 | 0.9 | 75 | 1.0 | 74 | 0.9 | 73 | 0.9 | 129 | 1.6 | 118 | 1.5 | 89 | 1.1 | 112 | 1.4 |
| 8 | 50 | 0.6 | 52 | 0.7 | 57 | 0.7 | 53 | 0.7 | 100 | 1.3 | 92 | 1.2 | 84 | 1.1 | 92 | 1.2 |
| 9 | 41 | 0.5 | 39 | 0.5 | 48 | 0.6 | 43 | 0.5 | 71 | 0.9 | 65 | 0.8 | 61 | 0.8 | 66 | 0.8 |
| 10 | 35 | 0.4 | 37 | 0.5 | 31 | 0.4 | 34 | 0.4 | 42 | 0.5 | 40 | 0.5 | 45 | 0.6 | 42 | 0.5 |
| Total | 597 | | 619 | | 657 | | 625 | | 775 | | 742 | | 757 | | 759 | |

Note: Data are similar to shoaling volumes which can be determined from hydrographic surveys (from a postdredge survey to the following predredge survey).

Table 4

Dredging History of Galveston Channel, Millions of Cubic Yards

| Fiscal Year | Annual New Work | Accumulated New Work | Annual Maintenance |
|---|---|---|---|
| 1902 | 0.102 | 0. | 0. |
| 1903 | 0.485 | 0.102 | 0. |
| 1904 | 2.237 | 0.587 | 0. |
| 1905 | 0.344 | 2.824 | 0. |
| 1906 | 0.518 | 3.168 | 0.109 |
| 1907 | 0.535 | 3.686 | 0.604 |
| 1908 | 2.018 | 4.221 | 0. |
| 1909 | 0.700 | 6.239 | 0.190 |
| 1910 | 0.138 | 6.939 | 2.186 |
| 1911 | 0.197 | 7.077 | 0.944 |
| 1912 | 5.511 | 7.274 | 1.541 |
| 1913 | 1.187 | 12.785 | 0. |
| 1914 | 1.166 | 13.972 | 0.044 |
| 1915 | 0. | 15.138 | 1.793 |
| 1916 | 0. | 15.138 | 1.008 |
| 1917 | 0. | 15.138 | 2.130 |
| 1918 | 0. | 15.138 | 1.227 |
| 1919 | 0. | 15.138 | 0. |
| 1920 | 0. | 15.138 | 0.273 |
| 1921 | 0. | 15.138 | 1.002 |
| 1922 | 0. | 15.138 | 1.321 |
| 1923 | 0. | 15.138 | 1.795 |
| 1924 | 0. | 15.138 | 3.095 |
| 1925 | 0. | 15.138 | 1.709 |
| 1926 | 0. | 15.138 | 3.220 |
| 1927 | 0. | 15.138 | 5.322 |
| 1928 | 0. | 15.138 | 5.271 |
| 1929 | 4.515 | 15.138 | 0.149 |
| 1930 | 0. | 19.653 | 2.849 |
| 1931 | 0. | 19.653 | 2.035 |
| 1932 | 0. | 19.653 | 3.682 |
| 1933 | 0. | 19.653 | 0. |
| 1934 | 0. | 19.653 | 4.725 |
| 1935 | 0. | 19.653 | 0.889 |
| 1936 | 0. | 19.653 | 3.172 |
| 1937 | 0.192 | 19.653 | 0.384 |
| 1938 | 0.848 | 19.845 | 3.247 |
| 1939 | 0. | 20.693 | 0.828 |
| 1940 | 0. | 20.693 | 3.646 |
| 1941 | 0. | 20.693 | 0. |

(Continued)

Note: Data taken from CE Annual Reports.

Table 4 (Concluded)

| Fiscal Year | Annual New Work | Accumulated New Work | Annual Maintenance |
|---|---|---|---|
| 1942 | 0. | 20.693 | 0. |
| 1943 | 0. | 20.693 | 5.198 |
| 1944 | 0. | 20.693 | 0.456 |
| 1945 | 0. | 20.693 | 4.969 |
| 1946 | 0. | 20.693 | 0. |
| 1947 | 0. | 20.693 | 6.083 |
| 1948 | 0. | 20.693 | 0. |
| 1949 | 0. | 20.693 | 0. |
| 1950 | 0. | 20.693 | 5.005 |
| 1951 | 0. | 20.693 | 0. |
| 1952 | 0. | 20.693 | 3.212 |
| 1953 | 0. | 20.693 | 2.895 |
| 1954 | 0. | 20.693 | 0. |
| 1955 | 0. | 20.693 | 2.733 |
| 1956 | 0. | 20.693 | 1.169 |
| 1957 | 0. | 20.693 | 0. |
| 1958 | 0. | 20.693 | 2.150 |
| 1959 | 0. | 20.693 | 0. |
| 1960 | 0. | 20.693 | 1.601 |
| 1961 | 0. | 20.693 | 2.431 |
| 1962 | 1.000 | 20.693 | 3.599 |
| 1963 | 0. | 21.693 | 0.888 |
| 1964 | 0. | 21.693 | 4.599 |
| 1965 | 0. | 21.693 | 3.535 |
| 1966 | 2.273 | 21.693 | 0.233 |
| 1967 | 1.566 | 23.966 | 1.003 |
| 1968 | 0. | 25.532 | 0. |
| 1969 | 0. | 25.532 | 4.313 |
| 1970 | 0. | 25.532 | 0. |
| 1971 | 0. | 25.532 | 0.705 |
| 1972 | 0. | 25.532 | 3.293 |
| 1973 | 0. | 25.532 | 0. |
| 1974 | 0. | 25.532 | 3.483 |
| 1975 | 1.568 | 25.532 | 0. |

Table 5

Galveston Channel Shoaling Rates Computed from Dredging Volumes

| Channel Dimensions ft | Accumulated New Work* | Maintenance Dredging FY | From | To | Volume* | Shoaling Interval From | To | Years | Computed Shoaling Rate* | Computed Average Shoaling Rate* |
|---|---|---|---|---|---|---|---|---|---|---|
| Pre 30 × 1200 | 3,168 | 1905-07 | 8 Aug 04 | 30 Jun 07 | 711 | 8 Aug 04 | 30 Jun 07 | 2.89 | 246 | 246 |
| Pre 30 × 1200 | 7,077 | 1908-12 | 1 Jul 07 | 30 Jun 12 | 4,860 | 1 Jul 07 | 30 Jun 12 | 5.00 | 972 | 972 |
| Pre 30 × 1200 | 13,972 | 1913-15 | 1 Jul 12 | 30 Jun 15 | 1,836 | 1 Jul 12 | 30 Jun 15 | 3.00 | 612 | 612 |
| 30 × 1200 | 15,138 | 1916 | 27 Oct 15 | 18 Apr 16 | 1,008 | 1 Jul 15 | 18 Apr 16 | 0.80 | 1,260 | |
| (plus 2 ft | | 1915-18 | 12 Aug 16 | 13 Dec 17 | 3,358 | 19 Apr 16 | 13 Dec 17 | 1.65 | 2,029 | |
| allowable | | 1918-20 | 15 Nov 19 | 15 Jan 20 | 217 | 14 Dec 17 | 15 Jan 20 | 2.05 | 106 | |
| dredging | | 1920 | 16 Jan 20 | 30 Mar 20 | 56 | 16 Jan 20 | 30 Mar 20 | 0.24 | 230 | |
| tolerance) | | 1920-24 | 1 Jul 20 | 13 Apr 24 | 7,215 | 31 Mar 20 | 13 Apr 24 | 4.04 | 1,786 | |
| | | 1924-25 | 1 Jul 24 | 26 Oct 24 | 222 | 14 Apr 24 | 26 Oct 24 | 0.54 | 413 | |
| | | 1925 | 9 Oct 24 | 14 Jun 25 | 1,487 | 27 Oct 24 | 14 Jun 25 | 0.63 | 2,350 | |
| | | 1925-29 | 25 Jul 25 | 20 Jul 28 | 13,963 | 15 Jun 25 | 20 Jul 28 | 3.10 | 4,506 | 2,108 |
| 32 × 1200 | 19,653 | 1929-31 | 24 Mar 30 | 25 Sep 30 | 4,885 | 21 Jul 28 | 25 Sep 30 | 2.18 | 2,237 | |
| (plus 2 ft | | 1931-32 | 7 Dec 31 | 4 Mar 32 | 3,680 | 26 Sep 30 | 4 Mar 32 | 1.44 | 2,560 | |
| allowable | | 1932-34 | 1 Sep 33 | 9 Feb 34 | 4,720 | 5 Mar 32 | 9 Feb 34 | 1.94 | 2,439 | |
| dredging | | 1934-36 | 1 May 35 | 26 Oct 35 | 4,060 | 10 Feb 34 | 26 Oct 35 | 1.71 | 2,375 | |
| tolerance) | | 1936-38 | 23 May 37 | 13 Nov 37 | 3,631 | 27 Oct 35 | 13 Nov 37 | 2.05 | 1,772 | 2,252 |
| 34 × 1200 | 20,693 | 1938-39 | 9 Mar 39 | 7 Jun 39 | 830 | 14 Nov 37 | 7 Jun 39 | 1.56 | 529 | |
| (plus 2 ft | | 1939-40 | 16 Jan 40 | 24 May 40 | 3,650 | 8 Jun 39 | 24 May 40 | 0.96 | 3,791 | |
| allowable | | 1940-44 | 1 Oct 42 | 16 Jul 43 | 5,664 | 25 May 40 | 16 Jul 43 | 3.15 | 1,798 | |
| dredging | | 1944-45 | 6 Sep 44 | 4 Nov 44 | 4,970 | 17 Jul 43 | 4 Nov 44 | 1.30 | 3,810 | |
| tolerance) | | 1945-47 | 12 Dec 46 | 25 Jun 47 | 6,080 | 5 Nov 44 | 25 Jun 47 | 2.64 | 2,306 | |
| | | 1947-50 | 1 Jul 49 | 9 Jan 50 | 5,000 | 26 Jun 47 | 9 Jan 50 | 2.54 | 1,968 | |

(Continued)

Note: Dredging volumes are similar to data available in CE Annual Reports; dates of surveys may be in CE Annual Reports or in district files.

* In thousands of cubic yards.

Table 5 (Concluded)

| Channel Dimensions ft | Accumulated New Work | Maintenance Dredging FY | From | To | Volume | Shoaling Interval From | To | Years | Computed Shoaling Rate | Computed Average Shoaling Rate |
|---|---|---|---|---|---|---|---|---|---|---|
| 34 × 1200 (plus 2 ft allowable dredging tolerance) (Cont'd) | 20,693 (Cont'd) | 1950-52 | 17 Jul 51 | 23 Oct 51 | 3,210 | 10 Jan 50 | 23 Oct 51 | 1.79 | 1,798 | |
| | | 1952-53 | 12 Feb 53 | 24 Apr 53 | 2,890 | 24 Oct 51 | 24 Apr 53 | 1.50 | 1,928 | |
| | | 1953-56 | 31 Mar 55 | 21 Aug 55 | 3,900 | 25 Apr 53 | 21 Aug 55 | 2.33 | 1,678 | |
| | | 1956-58 | 31 Mar 58 | 15 Jun 58 | 2,150 | 22 Aug 55 | 15 Jun 58 | 2.82 | 763 | |
| | | 1958-61 | 6 Mar 60 | 11 Dec 60 | 4,030 | 16 Jun 58 | 11 Dec 60 | 2.49 | 1,619 | |
| | | 1961-63 | 12 Jan 62 | 23 Jul 62 | 4,488 | 12 Dec 60 | 23 Jul 62 | 1.61 | 2,781 | 1,898 |
| 34 × 1200 (plus 2 ft allowable dredging tolerance and 2 ft advance maintenance) | 21,693 | 1963-64 | 1 Jul 63 | 30 Jun 64 | 4,606 | 24 Jul 62 | 30 Jun 64 | 1.94 | 2,374 | |
| | | 1964-66 | 1 Jul 64 | 21 Jul 65 | 3,640 | 1 Jul 64 | 21 Jul 65 | 1.05 | 3,451 | |
| | | 1966 | 22 Jul 65 | 20 Jun 66 | 128 | 22 Jul 65 | 20 Jun 66 | 0.92 | 139 | 2,140 |
| Transition | | 1967 | 1 Jul 66 | 21 Nov 66 | 1,003 | 21 Jun 66 | 21 Nov 66 | 0.42 | 2,377 | 2,377 |
| 36 × 1200 (plus 2 ft allowable dredging tolerance and 2 ft advance maintenance) | | 1967-69 | 20 Dec 68 | 2 Jun 69 | 4,310 | 22 Nov 66 | 2 Jun 69 | 2.53 | 1,706 | |
| | | 1969-72 | 1 Jul 71 | 28 Oct 71 | 3,780 | 3 Jun 69 | 28 Oct 71 | 2.41 | 1,662 | |
| | | 1972-74 | 28 Jan 74 | 1 Jun 74 | 3,480 | 29 Oct 71 | 1 Jun 74 | 2.59 | 1,344 | 1,567 |

Table 6

Galveston Channel Shoaling

Thousands of Cubic Yards per Year and in Feet per Year

| Channel Section | 34-ft* Channel May 60 to Jan 62 thou cu yd | ft/yr | 34-ft* Channel with 2 ft Advance Maintenance: Jul 62 to Jul 65 thou cu ft | ft/yd | Mar 62 to Apr 64 thou cu ft | ft/yd | May 64 to Jun 65 thou cu ft | ft/yd | Jul 65 to Jun 66 thou cu ft | ft/yd | Avg thou cu ft | ft/yd | 36-ft Channel with 3 ft Advance Maintenance*: Sep 66 to Mar 69 thou cu ft | ft/yd | May 69 to Feb 71 thou cu ft | ft/yd | Oct 71 to Mar 74 thou cu ft | ft/yd | May 74 to Aug 75 thou cu ft | ft/yd | Avg thou cu ft | ft/yd |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 256 | 2.9 | -- | -- | 190 | 2.1 | 283 | 3.2 | 246 | 2.8 | 227 | 2.6 | 163 | 2.4 | 184 | 2.8 | 216 | 3.2 | 179 | 2.7 | 186 | 2.8 |
| 2 | 240 | 2.7 | -- | -- | 188 | 2.1 | 306 | 3.4 | 224 | 2.5 | 227 | 2.6 | 204 | 2.3 | 209 | 2.4 | 218 | 2.5 | 194 | 2.2 | 208 | 2.3 |
| 3 | 251 | 2.8 | -- | -- | 235 | 2.6 | 283 | 3.2 | 162 | 1.8 | 231 | 2.6 | 193 | 2.2 | 176 | 2.0 | 199 | 2.2 | 184 | 2.1 | 189 | 2.1 |
| 4 | 186 | 2.1 | -- | -- | 107 | 1.2 | 201 | 2.3 | 115 | 1.3 | 134 | 1.5 | 133 | 1.5 | 126 | 1.4 | 162 | 1.8 | 190 | 2.1 | 149 | 1.7 |
| 5 | 150 | 1.7 | 139 | 1.6 | -- | -- | -- | -- | 172 | 1.9 | 147 | 1.7 | 146 | 1.6 | 108 | 1.2 | 142 | 1.6 | 84 | 0.9 | 126 | 1.4 |
| 6 | 209 | 2.4 | 133 | 1.5 | -- | -- | -- | -- | 218 | 2.5 | 153 | 1.7 | 128 | 1.4 | 142 | 1.6 | 169 | 1.9 | 145 | 1.6 | 146 | 1.6 |
| 7 | 251 | 2.8 | 133 | 1.5 | -- | -- | -- | -- | 253 | 2.8 | 162 | 1.8 | 186 | 2.1 | 188 | 2.1 | 176 | 2.0 | 184 | 2.1 | 183 | 2.1 |
| 8 | 113 | 1.3 | 180 | 2.0 | -- | -- | -- | -- | 318 | 3.6 | 213 | 2.4 | 223 | 2.5 | 204 | 2.3 | 199 | 2.2 | 233 | 2.6 | 213 | 2.4 |
| 9 | 82 | 0.9 | 152 | 1.7 | -- | -- | -- | -- | 228 | 2.6 | 170 | 1.9 | 210 | 2.4 | 216 | 2.4 | 163 | 1.8 | 264 | 3.0 | 206 | 2.3 |
| 10 | 45 | 0.5 | 99 | 1.1 | -- | -- | -- | -- | 173 | 1.9 | 117 | 1.3 | 227 | 2.6 | 207 | 2.3 | 177 | 2.0 | 216 | 2.4 | 205 | 2.3 |
| Total | 1,788 | | | | | | | | | | 1,781 | | | | | | | | | | 1,811 | |

Note: -- Surveys not available (no data).
* Plus 2 ft allowable dredging tolerance.

Table 7

Dredging History of Texas City Channel, Millions of Cubic Yards

| Fiscal Year | Annual New Work | Accumulated New Work | Annual Maintenance |
|---|---|---|---|
| 1901 | 0.815 | 0. | 0. |
| 1902 | 0.967 | 0.815 | 0. |
| 1903 | 1.105 | 1.782 | 0. |
| 1904 | 0.684 | 2.887 | 0. |
| 1905 | 1.010 | 3.571 | 0. |
| 1906 | 0. | 4.581 | 0.698 |
| 1907 | 0. | 4.581 | 0. |
| 1908 | 0. | 4.581 | 1.001 |
| 1909 | 0. | 4.581 | 0.273 |
| 1910 | 0. | 4.581 | 0.700 |
| 1911 | 1.153 | 4.581 | 0.100 |
| 1912 | 0. | 5.734 | 0.225 |
| 1913 | 0.072 | 5.734 | 1.155 |
| 1914 | 0.465 | 5.806 | 0.657 |
| 1915 | 3.639 | 6.271 | 0.353 |
| 1916 | 2.524 | 9.910 | 0.430 |
| 1917 | 0. | 12.434 | 0.666 |
| 1918 | 0. | 12.434 | 1.177 |
| 1919 | 0. | 12.434 | 0.458 |
| 1920 | 0. | 12.434 | 0.585 |
| 1921 | 0. | 12.434 | 0.626 |
| 1922 | 0. | 12.434 | 0.796 |
| 1923 | 0. | 12.434 | 0. |
| 1924 | 0. | 12.434 | 0.287 |
| 1925 | 0. | 12.434 | 2.226 |
| 1926 | 0. | 12.434 | 4.240 |
| 1927 | 0. | 12.434 | 0.056 |
| 1928 | 0. | 12.434 | 2.396 |
| 1929 | 0. | 12.434 | 1.940 |
| 1930 | 0. | 12.434 | 2.451 |
| 1931 | 1.840 | 12.434 | 1.288 |
| 1932 | 0. | 14.274 | 1.002 |
| 1933 | 0. | 14.274 | 2.932 |
| 1934 | 0. | 14.274 | 0. |
| 1935 | 0. | 14.274 | 1.921 |
| 1936 | 0. | 14.274 | 0. |
| 1937 | 1.846 | 14.274 | 0.980 |
| 1938 | 0. | 16.120 | 0. |
| 1939 | 0. | 16.120 | 1.083 |
| 1940 | 0. | 16.120 | 1.425 |

(Continued)

Note: Data taken from CE Annual Reports.

Table 7 (Concluded)

| Fiscal Year | Annual New Work | Accumulated New Work | Annual Maintenance |
|---|---|---|---|
| 1941 | 0. | 16.120 | 0.385 |
| 1942 | 0. | 16.120 | 1.973 |
| 1943 | 0. | 16.120 | 0.173 |
| 1944 | 0. | 16.120 | 0.659 |
| 1945 | 0. | 16.120 | 1.879 |
| 1946 | 0. | 16.120 | 0. |
| 1947 | 0. | 16.120 | 0. |
| 1948 | 0. | 16.120 | 3.348 |
| 1949 | 0. | 16.120 | 0. |
| 1950 | 0. | 16.120 | 1.946 |
| 1951 | 0. | 16.120 | 0. |
| 1952 | 0. | 16.120 | 1.329 |
| 1953 | 0. | 16.120 | 0. |
| 1954 | 0. | 16.120 | 1.503 |
| 1955 | 0. | 16.120 | 0. |
| 1956 | 0. | 16.120 | 1.250 |
| 1957 | 0. | 16.120 | 0. |
| 1958 | 0. | 16.120 | 1.718 |
| 1959 | 2.145 | 16.120 | 0. |
| 1960 | 3.884 | 18.265 | 0.818 |
| 1961 | 0. | 22.149 | 0. |
| 1962 | 0. | 22.149 | 3.502 |
| 1963 | 0. | 22.149 | 1.245 |
| 1964 | 0. | 22.149 | 1.286 |
| 1965 | 0. | 22.149 | 3.639 |
| 1966 | 1.143 | 22.149 | 0.058 |
| 1967 | 5.027 | 23.292 | 1.368 |
| 1968 | 1.143 | 28.319 | 2.923 |
| 1969 | 0. | 29.462 | 0. |
| 1970 | 0. | 29.462 | 3.048 |
| 1971 | 0. | 29.462 | 0. |
| 1972 | 0. | 29.462 | 1.700 |
| 1973 | 0. | 29.462 | 1.045 |
| 1974 | 0. | 29.462 | 0. |
| 1975 | 0. | 29.462 | 3.258 |

Table 8

Texas City Channel Shoaling Rates Computed from Dredging Volumes

| Channel Dimensions ft | Accumulated New Work* | Maintenance Dredging FY | Maintenance Dredging From | Maintenance Dredging To | Maintenance Dredging Volume* | Shoaling Interval From | Shoaling Interval To | Shoaling Interval Years | Computed Shoaling Rate* | Computed Average Shoaling Rate* |
|---|---|---|---|---|---|---|---|---|---|---|
| 25 × 100 | 4,581 | 1906 | 1 Jul 05 | 7 Jun 06 | 698 | 1 Jul 05 | 7 Jun 06 | 0.91 | 767 | |
| | | 1906-08 | 8 Jul 07 | 19 Sep 07 | 1,001 | 8 Jun 06 | 19 Sep 07 | 1.31 | 763 | |
| | | 1908-09 | 1 Nov 08 | 15 Nov 08 | 273 | 20 Sep 07 | 15 Nov 08 | 1.16 | 236 | |
| | | 1909-10 | 22 Sep 09 | 18 Apr 10 | 700 | 16 Nov 08 | 18 Apr 10 | 1.42 | 492 | |
| | | 1910-11 | 22 May 11 | 29 Jun 11 | 100 | 19 Apr 10 | 29 Jun 11 | 1.20 | 84 | 462 |
| Transition | 5,734 | 1911-12 | 2 Oct 11 | 24 Oct 11 | 225 | 30 Jun 11 | 24 Oct 11 | 0.32 | 702 | |
| | | 1912-13 | 8 Sep 12 | 17 Dec 12 | 1,039 | 25 Oct 11 | 17 Dec 12 | 1.15 | 905 | |
| | | 1913 | 8 Sep 12 | 15 May 13 | 116 | 18 Dec 12 | 15 May 13 | 0.41 | 284 | 735 |
| Transition | 5,806 | 1913-14 | 11 Aug 13 | 16 Jan 14 | 657 | 16 May 13 | 16 Jan 14 | 0.67 | 975 | 975 |
| Transition | 5,882 | 1914-15 | 12 Aug 14 | 9 Nov 14 | 353 | 17 Jan 14 | 9 Nov 14 | 0.81 | 437 | 437 |
| Transition | 9,910 | 1915-16 | 1 Jul 15 | 30 Jun 16 | 430 | 10 Nov 14 | 30 Jun 16 | 1.64 | 262 | 262 |
| 30 × 300 | 12,434 | 1917 | 28 Aug 16 | 4 Oct 16 | 666 | 1 Jul 16 | 4 Oct 16 | 0.26 | 2,531 | |
| (plus 2 ft | | 1917-19 | 1 Feb 18 | 23 Aug 18 | 1,635 | 5 Oct 16 | 23 Aug 18 | 1.88 | 867 | |
| allowable | | 1919-20 | 27 Sep 19 | 18 Nov 19 | 409 | 24 Aug 18 | 18 Nov 19 | 1.24 | 330 | |
| dredging | | 1920 | 29 Dec 19 | 31 Jan 20 | 176 | 19 Nov 19 | 31 Jan 20 | 0.20 | 868 | |
| tolerance) | | 1920-21 | 19 Nov 20 | 9 Mar 21 | 626 | 1 Feb 20 | 9 Mar 21 | 1.10 | 568 | |
| | | 1921-22 | 1 Dec 21 | 30 Jun 22 | 796 | 10 Mar 21 | 30 Jun 22 | 1.31 | 608 | |
| | | 1923-24 | 24 Dec 23 | 16 Mar 24 | 287 | 1 Jul 22 | 16 Mar 24 | 1.71 | 168 | |
| | | 1924-27 | 1 Jul 24 | 6 Jul 26 | 6,522 | 17 Mar 24 | 6 Jul 26 | 2.31 | 2,867 | |
| | | 1927-29 | 1 Jul 28 | 11 Oct 28 | 3,061 | 7 Jul 26 | 11 Oct 28 | 2.27 | 1,351 | |
| | | 1929 | 1 Nov 28 | 21 Dec 28 | 1,177 | 12 Oct 28 | 21 Dec 28 | 0.19 | 6,052 | |
| | | 1929 | 21 May 29 | 7 Jun 29 | 98 | 22 Dec 28 | 7 Jun 29 | 0.46 | 213 | |
| | | 1929-30 | 12 Jul 29 | 30 Jan 30 | 2,451 | 8 Jun 29 | 30 Jan 30 | 0.65 | 3,774 | |
| | | 1930-31 | 23 Sep 30 | 15 May 31 | 1,288 | 31 Jan 30 | 15 May 31 | 1.29 | 1,000 | 1,290 |

(Continued)

Note: Dredging volumes are similar to data available in CE Annual Reports; dates of surveys may be in CE Annual Reports or in district files.

* In thousands of cubic yards.

Table 8 (Continued)

| Channel Dimensions ft | Accumulated New Work | Maintenance Dredging FY | Maintenance Dredging From | Maintenance Dredging To | Maintenance Dredging Volume | Shoaling Interval From | Shoaling Interval To | Shoaling Interval Years | Computed Shoaling Rate | Computed Average Shoaling Rate |
|---|---|---|---|---|---|---|---|---|---|---|
| 30 × 300 | 14,274 | 1931-32 | 4 Mar 32 | 25 Mar 32 | 1,002 | 16 May 31 | 25 Mar 32 | 0.86 | 1,165 | |
| (plus 2 ft | | 1932-33 | 9 Nov 32 | 25 Jan 33 | 2,932 | 26 Mar 32 | 25 Jan 33 | 0.84 | 3,498 | |
| allowable | | 1933-35 | 19 Nov 34 | 23 Jan 35 | 1,921 | 26 Jan 33 | 23 Jan 35 | 1.99 | 963 | |
| dredging tol- | | 1935-37 | 23 Oct 36 | 4 Feb 37 | 980 | 24 Jan 35 | 4 Feb 37 | 2.03 | 482 | 1,194 |
| erance) harbor | | | | | | | | | | |
| extended | | | | | | | | | | |
| 34 × 300 | 16,120 | 1937-39 | 1 Feb 39 | 15 Apr 39 | 763 | 5 Feb 37 | 15 Apr 39 | 2.19 | 348 | |
| (plus 2 ft | | 1939 | 1 May 39 | 30 Jun 39 | 300 | 16 Apr 39 | 30 Jun 39 | 0.21 | 1,442 | |
| allowable | | 1939-40 | 14 Feb 40 | 30 Jun 40 | 1,425 | 1 Jul 39 | 30 Jun 40 | 1.00 | 1,425 | |
| dredging | | 1940-41 | 7 Mar 41 | 4 May 41 | 385 | 1 Jul 40 | 4 May 41 | 0.84 | 456 | |
| tolerance) | | 1941-43 | 27 Mar 42 | 5 Jul 42 | 2,146 | 5 May 41 | 5 Jul 42 | 1.17 | 1,834 | |
| | | 1943-45 | 17 May 44 | 23 Aug 44 | 2,538 | 6 Jul 42 | 23 Aug 44 | 2.13 | 1,189 | |
| | | 1945-48 | 23 Aug 47 | 5 Oct 47 | 2,925 | 24 Aug 44 | 5 Oct 47 | 3.12 | 938 | |
| | | 1948 | 10 Oct 47 | 28 Oct 47 | 423 | 6 Oct 47 | 28 Oct 47 | 0.06 | 6,712 | |
| | | 1948-50 | 31 Jan 50 | 28 Mar 50 | 1,946 | 29 Oct 47 | 28 Mar 50 | 2.41 | 806 | |
| | | 1950-52 | 27 Feb 52 | 12 Mar 52 | 1,329 | 29 Mar 50 | 12 Mar 52 | 1.96 | 679 | |
| | | 1952-54 | 13 Jan 54 | 25 Feb 54 | 1,503 | 13 Mar 52 | 25 Feb 54 | 1.96 | 767 | |
| | | 1954-56 | 20 Oct 55 | 20 Nov 55 | 1,250 | 26 Feb 54 | 20 Nov 55 | 1.73 | 721 | |
| | | 1956-58 | 9 Nov 57 | 18 Jan 58 | 1,718 | 21 Nov 55 | 18 Jan 58 | 2.16 | 795 | |
| | | 1958-60 | 1 Jul 59 | 10 Apr 60 | 818 | 19 Jan 58 | 10 Apr 60 | 2.22 | 368 | 840 |
| 36 × 400 | 22,149 | 1960-62 | 18 Nov 61 | 14 Feb 62 | 3,502 | 11 Apr 60 | 14 Feb 62 | 1.85 | 1,894 | |
| (plus 2 ft | | 1962-64 | 26 May 63 | 30 Jun 64 | 2,531 | 15 Feb 62 | 30 Jun 64 | 2.37 | 1,067 | |
| allowable | | 1965 | 19 Jan 65 | 7 May 65 | 3,639 | 1 Jul 64 | 7 May 65 | 0.85 | 4,270 | |
| dredging tol- | | 1965-67 | 16 May 66 | 13 Jun 67 | 1,368 | 8 May 65 | 13 Jun 67 | 2.10 | 679 | 1,547 |
| erance and 2 | | | | | | | | | | |
| ft advance | | | | | | | | | | |
| maintenance) | | | | | | | | | | |
| Transition | 28,319 | 1967-68 | 1 Jul 67 | 30 Jun 68 | 2,923 | 14 Jun 67 | 30 Jun 68 | 1.05 | 2,793 | 2,793 |

(Continued)

Table 8 (Concluded)

| Channel Dimensions ft | Accumulated New Work | Maintenance Dredging | | | | Shoaling Interval | | | Computed Shoaling Rate | Computed Average Shoaling Rate |
|---|---|---|---|---|---|---|---|---|---|---|
| | | FY | From | To | Volume | From | To | Years | | |
| 40 × 400 (plus 2 ft allowable dredging tolerance and 3 ft advance maintenance) | 29,462 | 1969-70 | 4 Feb 70 | 17 Apr 70 | 3,048 | 1 Jul 68 | 17 Apr 70 | 1.80 | 1,696 | |
| | | 1970-73 | 13 May 72 | 7 Jul 72 | 2,745 | 18 Apr 70 | 7 Jul 72 | 2.22 | 1,235 | |
| | | 1973-75 | 24 Aug 74 | 2 Jan 75 | 3,258 | 8 Jul 72 | 2 Jan 75 | 2.49 | 1,308 | 1,390 |

Table 9

Texas City Channel Shoaling

Thousands of Cubic Yards per Year and in Feet per Year

| | 36-ft Channel with 2 to 3 ft Advance Maintenance | | | | | | | | 40-ft Channel with 3 ft Advance Maintenance | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan [illegible] to Jun 63 | | Jul 63 to Sep 64 | | Apr 65 to Aug 66 | | Avg | | Aug 66 to Mar 68 | | Apr 68 to Mar 70 | | Apr [illegible] to Jan [illegible] | | May [illegible] to Oct [illegible] | | Avg | |
| [illegible] | thou cu yd | ft/yr | thou cu yd | ft/yr | thou cu yd | ft/yr | thou cu yd | ft/yr | thou cu yd | ft/yr | thou cu yd | ft/yr | thou cu yd | ft/yr | thou cu yd | ft/yr | thou cu yd | ft/yr |
| 1 | 239 | 2.0 | 261 | 2.2 | 368 | 3.1 | 291 | 2.5 | -- | -- | 178 | 1.5 | -- | -- | -- | -- | 178 | 1.5 |
| 2 | 143 | 2.4 | 220 | 3.7 | 80 | 1.4 | 143 | 2.4 | 397 | 6.7 | 127 | 2.1 | 103 | 1.7 | 87 | 1.5 | 162 | 2.7 |
| 3 | 212 | 3.6 | 163 | 2.8 | 156 | 2.6 | 177 | 3.0 | 370 | 6.2 | 133 | 2.2 | 182 | 3.1 | 129 | 2.2 | 190 | 3.[illegible] |
| 4 | 178 | 3.0 | 120 | 2.0 | 90 | 1.5 | 129 | 2.2 | 240 | 4.1 | 144 | 2.4 | 190 | 3.2 | 136 | 2.3 | 171 | 2.9 |
| 5 | 173 | 2.9 | 159 | 2.7 | 111 | 1.9 | 147 | 2.5 | 215 | 3.6 | 125 | 2.1 | 179 | 3.0 | 133 | 2.2 | 158 | 2.7 |
| 6 | 189 | 3.2 | 147 | 2.5 | 100 | 1.7 | 145 | 2.4 | 237 | 4.0 | 167 | 2.8 | 220 | 3.7 | 158 | 2.7 | 190 | 3.2 |
| 7 | 230 | 3.9 | 180 | 3.0 | 167 | 2.8 | 193 | 3.3 | 269 | 4.5 | 240 | 4.1 | 273 | 4.6 | 201 | 3.4 | 241 | 4.1 |
| 8 | 307 | 5.2 | 254 | 4.3 | 162 | 2.7 | 239 | 4.0 | 305 | 5.1 | 291 | 4.9 | 320 | 5.4 | 174 | 2.9 | 263 | 4.4 |
| 9 | 92 | 1.6 | 42 | 0.7 | 69 | 1.2 | 69 | 1.2 | 204 | 3.4 | 106 | 1.8 | 49 | 0.8 | 44 | 0.7 | 93 | 1.6 |
| Total | | | | | | | 1,533 | | | | | | | | | | 1,646 | |

Note: -- surveys not available (no data).

Table 10

Dredging History of Houston Ship Channel, Galveston Bay Section

Millions of Cubic Yards

| Fiscal Year | Annual New Work | Accumulated New Work | Annual Maintenance |
|---|---|---|---|
| 1873 | 0.059 | 0. | 0. |
| 1874 | 0. | 0.059 | 0. |
| 1875 | 0. | 0.059 | 0. |
| 1876 | 0.134 | 0.059 | 0. |
| 1877 | 0. | 0.193 | 0. |
| 1878 | 0. | 0.193 | 0. |
| 1879 | 0.075 | 0.193 | 0. |
| 1880 | 0.629 | 0.268 | 0. |
| 1881 | 0. | 0.897 | 0. |
| 1882 | 0.160 | 0.897 | 0. |
| 1883 | 0.962 | 1.057 | 0. |
| 1884 | 0. | 2.019 | 0. |
| 1885 | 0. | 2.019 | 0. |
| 1886 | 0. | 2.019 | 0. |
| 1887 | 0. | 2.019 | 0. |
| 1888 | 0.200 | 2.019 | 0. |
| 1889 | 1.618 | 2.219 | 0. |
| 1890 | 0.020 | 3.837 | 0. |
| 1891 | 0. | 3.857 | 0. |
| 1892 | 0. | 3.857 | 0. |
| 1893 | 0. | 3.857 | 0. |
| 1894 | 0. | 3.857 | 0. |
| 1895 | 0. | 3.857 | 0. |
| 1896 | 0. | 3.857 | 0. |
| 1897 | 0. | 3.857 | 0. |
| 1898 | 0. | 3.857 | 0. |
| 1899 | 0. | 3.857 | 0. |
| 1900 | 0. | 3.857 | 0. |
| 1901 | 0.325 | 3.857 | 0. |
| 1902 | 2.773 | 4.182 | 0. |
| 1903 | 1.221 | 6.955 | 0. |
| 1904 | 3.992 | 8.176 | 0. |
| 1905 | 1.566 | 12.168 | 0. |
| 1906 | 0. | 13.734 | 0. |
| 1907 | 0. | 13.734 | 0. |
| 1908 | 0. | 13.734 | 1.315 |
| 1909 | 0. | 13.734 | 2.540 |
| 1910 | 0. | 13.734 | 0. |
| 1911 | 0. | 13.734 | 0. |
| 1912 | 0. | 13.734 | 0. |

(Continued)

Note: Data taken from CE Annual Reports.

Table 10 (Continued)

| Fiscal Year | Annual New Work | Accumulated New Work | Annual Maintenance |
|---|---|---|---|
| 1913 | 0. | 13.734 | 0. |
| 1914 | 15.153 | 13.734 | 0. |
| 1915 | 0.004 | 28.887 | 0.187 |
| 1916 | 0. | 28.891 | 2.928 |
| 1917 | 0. | 28.891 | 3.908 |
| 1918 | 0. | 28.891 | 1.879 |
| 1919 | 0. | 28.891 | 0. |
| 1920 | 0. | 28.891 | 2.653 |
| 1921 | 10.599 | 28.891 | 0. |
| 1922 | 6.538 | 39.490 | 1.877 |
| 1923 | 0. | 46.028 | 3.383 |
| 1924 | 0. | 46.028 | 0. |
| 1925 | 0. | 46.028 | 3.547 |
| 1926 | 0. | 46.028 | 2.091 |
| 1927 | 0. | 46.028 | 2.982 |
| 1928 | 0. | 46.028 | 1.703 |
| 1929 | 0. | 46.028 | 1.696 |
| 1930 | 0. | 46.028 | 6.989 |
| 1931 | 0. | 46.028 | 0.346 |
| 1932 | 0. | 46.028 | 5.813 |
| 1933 | 0.043 | 46.028 | 0.028 |
| 1934 | 0. | 46.071 | 0.457 |
| 1935 | 11.850 | 46.071 | 1.831 |
| 1936 | 0. | 57.921 | 2.836 |
| 1937 | 5.615 | 57.921 | 3.858 |
| 1938 | 0. | 63.536 | 1.308 |
| 1939 | 0. | 63.536 | 3.044 |
| 1940 | 0. | 63.536 | 3.901 |
| 1941 | 0. | 63.536 | 3.352 |
| 1942 | 0. | 63.536 | 3.133 |
| 1943 | 0. | 63.536 | 5.519 |
| 1944 | 0. | 63.536 | 3.842 |
| 1945 | 0. | 63.536 | 5.198 |
| 1946 | 0. | 63.536 | 0. |
| 1947 | 0. | 63.536 | 0. |
| 1948 | 0. | 63.536 | 10.958 |
| 1949 | 0. | 63.536 | 0. |
| 1950 | 0.737 | 63.536 | 0.559 |
| 1951 | 7.663 | 64.273 | 4.553 |
| 1952 | 0. | 71.936 | 0. |
| 1953 | 0. | 71.936 | 4.477 |
| 1954 | 0. | 71.936 | 0. |
| 1955 | 0. | 71.936 | 4.764 |

(Continued)

Table 10 (Concluded)

| Fiscal Year | Annual New Work | Accumulated New Work | Annual Maintenance |
|---|---|---|---|
| 1956 | 0. | 71.936 | 0. |
| 1957 | 0. | 71.936 | 0. |
| 1958 | 0. | 71.936 | 0. |
| 1959 | 0. | 71.936 | 0. |
| 1960 | 0.228 | 71.936 | 4.130 |
| 1961 | 0.009 | 72.164 | 1.416 |
| 1962 | 0. | 72.173 | 0.047 |
| 1963 | 4.472 | 72.173 | 0.759 |
| 1964 | 4.320 | 76.645 | 2.147 |
| 1965 | 0. | 80.965 | 0.293 |
| 1966 | 0.213 | 80.965 | 5.888 |
| 1967 | 0. | 81.178 | 0.244 |
| 1968 | 0. | 81.178 | 0. |
| 1969 | 0. | 81.178 | 0.352 |
| 1970 | 0. | 81.178 | 6.272 |
| 1971 | 0. | 81.178 | 0. |
| 1972 | 0. | 81.178 | 3.720 |
| 1973 | 0. | 81.178 | 2.724 |
| 1974 | 0. | 81.178 | 1.393 |
| 1975 | 0. | 81.178 | 0.494 |

(Sheet 3 of 3)

Table 11

Dredging History of Houston Ship Channel, Buffalo Bayou Section

Millions of Cubic Yards

| Fiscal Year | Annual New Work | Accumulated New Work | Annual Maintenance |
|---|---|---|---|
| 1876 | 0.005 | 0. | 0. |
| 1877 | 0. | 0.005 | 0. |
| 1878 | 0. | 0.005 | 0. |
| 1879 | 0. | 0.005 | 0. |
| 1880 | 0. | 0.005 | 0. |
| 1881 | 0. | 0.005 | 0. |
| 1882 | 0.025 | 0.005 | 0. |
| 1883 | 0.099 | 0.030 | 0. |
| 1884 | 0.075 | 0.129 | 0. |
| 1885 | 0.079 | 0.204 | 0. |
| 1886 | 0.014 | 0.283 | 0. |
| 1887 | 0. | 0.297 | 0. |
| 1888 | 0.065 | 0.297 | 0. |
| 1889 | 0. | 0.362 | 0.060 |
| 1890 | 0.007 | 0.362 | 0. |
| 1891 | 0.026 | 0.369 | 0. |
| 1892 | 0. | 0.395 | 0. |
| 1893 | 0.023 | 0.395 | 0. |
| 1894 | 0.181 | 0.418 | 0. |
| 1895 | 0.170 | 0.599 | 0. |
| 1896 | 0.160 | 0.769 | 0. |
| 1897 | 0. | 0.929 | 0. |
| 1898 | 0. | 0.929 | 0. |
| 1899 | 0. | 0.929 | 0. |
| 1900 | 0. | 0.929 | 0. |
| 1901 | 0. | 0.929 | 0. |
| 1902 | 0. | 0.929 | 0. |
| 1903 | 0.074 | 0.929 | 0. |
| 1904 | 1.153 | 1.003 | 0. |
| 1905 | 1.150 | 2.156 | 0. |
| 1906 | 1.032 | 3.306 | 0.023 |
| 1907 | 1.260 | 4.338 | 0.040 |
| 1908 | 0.549 | 5.598 | 0.088 |
| 1909 | 0.991 | 6.147 | 0.185 |
| 1910 | 0.099 | 7.138 | 0. |
| 1911 | 0. | 7.237 | 0. |
| 1912 | 0.039 | 7.237 | 0. |
| 1913 | 8.339 | 7.276 | 0. |
| 1914 | 6.277 | 15.615 | 0. |
| 1915 | 0.277 | 21.892 | 0. |

(Continued)

Note: Data taken from CE Annual Reports.

Table 11 (Continued)

| Fiscal Year | Annual New Work | Accumulated New Work | Annual Maintenance |
|---|---|---|---|
| 1916 | 0. | 22.169 | 1.706 |
| 1917 | 0.138 | 22.169 | 0.725 |
| 1918 | 0. | 22.307 | 0.463 |
| 1919 | 0. | 22.307 | 0. |
| 1920 | 0. | 22.307 | 0.444 |
| 1921 | 1.463 | 22.307 | 2.158 |
| 1922 | 2.643 | 23.770 | 0.325 |
| 1923 | 5.712 | 26.413 | 0.865 |
| 1924 | 4.965 | 32.125 | 2.479 |
| 1925 | 2.786 | 37.090 | 2.669 |
| 1926 | 0.506 | 39.876 | 2.228 |
| 1927 | 0. | 40.382 | 2.895 |
| 1928 | 0. | 40.382 | 2.698 |
| 1929 | 0.260 | 40.382 | 4.050 |
| 1930 | 0. | 40.642 | 4.301 |
| 1931 | 0. | 40.642 | 1.480 |
| 1932 | 2.110 | 40.642 | 1.393 |
| 1933 | 3.051 | 42.752 | 0.096 |
| 1934 | 0.105 | 45.803 | 0.366 |
| 1935 | 2.516 | 45.908 | 3.398 |
| 1936 | 0.826 | 48.424 | 1.032 |
| 1937 | 0. | 49.250 | 0.450 |
| 1938 | 5.449 | 49.250 | 0.489 |
| 1939 | 3.752 | 54.699 | 0. |
| 1940 | 2.163 | 58.451 | 0.048 |
| 1941 | 1.371 | 60.614 | 0. |
| 1942 | 0. | 61.985 | 0.650 |
| 1943 | 0. | 61.985 | 2.304 |
| 1944 | 0. | 61.985 | 0.478 |
| 1945 | 0. | 61.985 | 0. |
| 1946 | 0. | 61.985 | 6.515 |
| 1947 | 0. | 61.985 | 0. |
| 1948 | 0. | 61.985 | 5.219 |
| 1949 | 0. | 61.985 | 3.896 |
| 1950 | 6.002 | 61.985 | 1.487 |
| 1951 | 2.209 | 67.987 | 0.527 |
| 1952 | 1.656 | 70.196 | 4.496 |
| 1953 | 2.329 | 71.852 | 1.150 |
| 1954 | 0. | 74.181 | 3.908 |
| 1955 | 0. | 74.181 | 0.575 |
| 1956 | 2.115 | 74.181 | 1.734 |
| 1957 | 0.832 | 76.296 | 2.403 |
| 1958 | 1.157 | 77.128 | 1.002 |

(Continued)

Table 11 (Concluded)

| Fiscal Year | Annual New Work | Accumulated New Work | Annual Maintenance |
|---|---|---|---|
| 1959 | 0.074 | 78.285 | 2.926 |
| 1960 | 2.178 | 78.359 | 1.342 |
| 1961 | 1.163 | 80.537 | 2.648 |
| 1962 | 6.020 | 81.700 | 3.788 |
| 1963 | 7.386 | 87.720 | 2.782 |
| 1964 | 3.470 | 95.106 | 2.155 |
| 1965 | 6.678 | 98.576 | 5.017 |
| 1966 | 1.977 | 105.254 | 1.336 |
| 1967 | 0. | 107.231 | 1.944 |
| 1968 | 0. | 107.231 | 2.651 |
| 1969 | 1.383 | 107.231 | 2.874 |
| 1970 | 0. | 108.614 | 2.989 |
| 1971 | 0.360 | 108.614 | 1.150 |
| 1972 | 0. | 108.974 | 2.251 |
| 1973 | 0. | 108.974 | 0.075 |
| 1974 | 0. | 108.974 | 0.254 |
| 1975 | 0. | 108.974 | 2.606 |

Table 12

Houston Ship Channel Shoaling Rates Computed from Dredging Volumes

Galveston Bay Section

| Channel Dimensions ft | Accumulated New Work* | Maintenance Dredging FY | From | To | Volume* | Shoaling Interval From | To | Years | Computed Shoaling Rate* | Computed Average Shoaling Rate* |
|---|---|---|---|---|---|---|---|---|---|---|
| 25 × 100 | 13,734 | 1905-08 | 19 Jan 08 | 28 Mar 08 | 1,315 | 14 Dec 04 | 28 Mar 08 | 3.29 | 400 | |
| | | 1908-09 | 1 Jul 08 | 31 Oct 08 | 2,440 | 29 Mar 08 | 31 Oct 08 | 0.59 | 4,272 | |
| | | 1909-16 | 11 Jun 15 | 16 Aug 15 | 1,305 | 1 Nov 08 | 16 Aug 15 | 6.79 | 192 | 484 |
| | 28,891 | 1916 | 1 Sep 15 | 30 Sep 15 | 220 | 17 Aug 15 | 30 Sep 15 | 0.12 | 1,784 | |
| | | 1916 | 8 Dec 15 | 28 Feb 16 | 1,401 | 1 Oct 15 | 28 Feb 16 | 0.42 | 3,387 | |
| | | 1916-17 | 8 Mar 16 | 7 Mar 17 | 4,097 | 1 Mar 16 | 7 Mar 17 | 1.02 | 4,020 | |
| | | 1917-18 | 1 Jul 17 | 19 Feb 18 | 1,879 | 8 Mar 17 | 19 Feb 18 | 0.96 | 1,965 | |
| | | 1918-20 | 20 Aug 19 | 10 Mar 20 | 2,653 | 20 Feb 18 | 10 Mar 20 | 2.05 | 1,293 | 2,246 |
| | 39,490 | 1920-23 | 1 Jul 21 | 30 Jun 23 | 5,260 | 11 Mar 20 | 30 Jun 23 | 3.31 | 1,591 | 1,591 |
| 30 × 250 | 46,028 | 1924-31 | 1 Jul 24 | 16 Sep 30 | 19,354 | 1 Jul 23 | 16 Sep 30 | 7.21 | 2,683 | |
| | | 1931-32 | 1 Jul 31 | 30 Jun 32 | 5,813 | 17 Sep 30 | 30 Jun 32 | 1.79 | 3,254 | 2,796 |
| | 46,071 | 1933-34 | 27 Jun 33 | 19 Feb 34 | 485 | 1 Jul 32 | 19 Feb 34 | 1.64 | 296 | |
| | | 1934-35 | 18 Nov 34 | 15 Feb 35 | 797 | 20 Feb 34 | 15 Feb 35 | 0.99 | 806 | 487 |
| 34 × 400 | 57,921 | 1935-36 | 7 Mar 35 | 6 Apr 36 | 3,870 | 16 Feb 35 | 6 Apr 36 | 1.14 | 3,404 | |
| | | 1936-37 | 4 Sep 36 | 21 Jun 37 | 3,858 | 7 Apr 36 | 21 Jun 37 | 1.21 | 3,193 | 3,295 |
| | 63,536 | 1937-39 | 25 Feb 38 | 31 Jan 39 | 4,352 | 22 Jun 37 | 31 Jan 39 | 1.61 | 2,697 | |
| | | 1939-41 | 1 Jul 39 | 6 Mar 41 | 7,253 | 1 Feb 39 | 6 Mar 41 | 2.09 | 3,465 | |
| | | 1941-42 | 14 Aug 41 | 24 Mar 42 | 2,852 | 7 Mar 41 | 24 Mar 42 | 1.05 | 2,719 | |
| | | 1942-43 | 1 Jun 42 | 4 Jan 43 | 5,799 | 25 Mar 42 | 4 Jan 43 | 0.78 | 7,401 | |
| | | 1943-44 | 16 Oct 43 | 20 Nov 43 | 212 | 5 Jan 43 | 20 Nov 43 | 0.88 | 242 | |

(Continued)

Note: Dredging volumes are similar to data available in CE Annual Reports; dates of surveys may be in CE Annual Reports or in district files.

* In thousands of cubic yards.

Table 12 (Concluded)

| Channel Dimensions ft | Accumulated New Work | Maintenance Dredging | | | | Shoaling Interval | | | Computed Shoaling Rate | Computed Average Shoaling Rate |
|---|---|---|---|---|---|---|---|---|---|---|
| | | FY | From | To | Volume | From | To | Years | | |
| 34 × 400 (Con't) | 63,536 (Con't) | 1944-45 | 1 Feb 44 | 3 Jul 44 | 3,749 | 21 Nov 43 | 3 Jul 44 | 0.62 | 6,082 | |
| | | 1945 | 9 Aug 44 | 15 Dec 44 | 5,079 | 4 Jul 44 | 15 Dec 44 | 0.45 | 11,235 | |
| | | 1945-48 | 16 Jul 47 | 31 Oct 47 | 8,746 | 16 Dec 44 | 31 Oct 47 | 2.88 | 3,040 | |
| | | 1948 | 4 Nov 47 | 12 Jan 48 | 2,212 | 1 Nov 47 | 12 Jan 48 | 0.20 | 11,064 | |
| | | 1948-51 | 28 May 50 | 24 Feb 51 | 5,112 | 13 Jan 48 | 24 Feb 51 | 3.12 | 1,640 | 3,316 |
| 36 × 400 | 71,936 | 1951-53 | 1 Jul 52 | 30 Jun 53 | 4,477 | 25 Feb 51 | 30 Jun 53 | 2.35 | 1,909 | |
| | | 1954-55 | 22 Nov 54 | 30 Mar 55 | 4,764 | 1 Jul 53 | 30 Mar 55 | 1.75 | 2,725 | |
| | | 1955-62 | 18 Mar 60 | 23 Oct 61 | 5,593 | 1 Apr 55 | 23 Oct 61 | 6.57 | 852 | 1,392 |
| | 72,173 | 1962-64 | 16 Mar 63 | 30 Jun 64 | 2,906 | 24 Oct 61 | 30 Jun 64 | 2.68 | 1,082 | 1,082 |
| 40 × 400 | 80,965 | 1965 | 21 Jul 64 | 26 Jul 64 | 66 | 1 Jul 64 | 26 Jul 64 | 0.07 | 925 | |
| | | 1965 | 13 Mar 65 | 12 Apr 65 | 227 | 27 Jul 64 | 12 Apr 65 | 0.71 | 319 | |
| | | 1965-67 | 3 Jan 66 | 7 Jul 66 | 6,132 | 13 Apr 65 | 7 Jul 66 | 1.24 | 4,963 | 3,182 |
| | 81,178 | 1967-70 | 16 Jun 69 | 3 Dec 69 | 6,624 | 8 Jul 66 | 3 Dec 69 | 3.41 | 1,944 | |
| | | 1970-72 | 23 Jul 71 | 22 Dec 71 | 3,720 | 4 Dec 69 | 22 Dec 71 | 2.05 | 1,813 | |
| | | 1972-73 | 28 Oct 72 | 2 Feb 73 | 2,724 | 23 Dec 71 | 2 Feb 73 | 1.12 | 2,443 | |
| | | 1973-75 | 6 Feb 74 | 12 Aug 74 | 1,887 | 3 Feb 73 | 12 Aug 74 | 1.52 | 1,239 | 1,847 |

Table 13

Houston Ship Channel Shoaling Rates Computed from Dredging Volumes

Buffalo Bayou Section

| Channel Dimensions ft | Accumulated New Work* | Maintenance Dredging | | | | Shoaling Interval | | | Computed Shoaling Rate* | Computed Average Shoaling Rate* |
|---|---|---|---|---|---|---|---|---|---|---|
| | | FY | From | To | Volume* | From | To | Years | | |
| 25 × 100 | 362 | 1888-89 | 6 Dec 88 | 30 Jun 89 | 60 | 18 Feb 88 | 30 Jun 89 | 1.33 | 45 | 45 |
| | 929 | 1890-1906 | 22 May 06 | 30 Jun 06 | 23 | 1 Jul 89 | 30 Jun 06 | 17.00 | 1 | 1 |
| | 4,338 | 1907 | 3 Jan 07 | 30 Jun 07 | 40 | 1 Jul 06 | 30 Jun 07 | 1.00 | 40 | 40 |
| | 5,598 | 1908 | 14 Dec 07 | 30 Jun 08 | 88 | 1 Jul 07 | 30 Jun 08 | 1.00 | 88 | 88 |
| | 6,147 | 1909 | 16 Nov 08 | 17 Mar 09 | 185 | 1 Jul 08 | 17 Mar 09 | 0.71 | 260 | 260 |
| | 7,276 | 1909-17 | 1 Mar 16 | 19 Jan 17 | 2,431 | 18 Mar 09 | 19 Jan 17 | 7.84 | 310 | 310 |
| | 22,307 | 1917-18 | 27 Mar 18 | 7 May 18 | 200 | 20 Jan 17 | 7 May 18 | 1.30 | 154 | |
| | | 1918 | 11 May 18 | 17 Jun 18 | 263 | 8 May 18 | 17 Jun 18 | 0.11 | 2,344 | |
| | | 1918-20 | 1 Feb 20 | 28 Feb 20 | 37 | 18 Jun 18 | 28 Feb 20 | 1.70 | 22 | 161 |
| 30 × 250 | 37,090 | 1920-31 | 25 Mar 20 | 28 Aug 30 | 25,402 | 29 Feb 20 | 28 Aug 30 | 10.50 | 2,420 | 2,420 |
| | 40,642 | 1931-32 | 19 Nov 30 | 5 Feb 32 | 2,316 | 29 Aug 30 | 5 Feb 32 | 1.44 | 1,607 | |
| | | 1932-33 | 29 Apr 32 | 29 Jul 32 | 326 | 6 Feb 32 | 29 Jul 32 | 0.48 | 684 | 1,378 |
| | 42,752 | 1933-34 | 1 Nov 33 | 31 Dec 34 | 338 | 30 Jul 32 | 31 Dec 34 | 1.42 | 237 | 237 |
| | 45,908 | 1934-35 | 25 Jun 34 | 3 Dec 34 | 1,762 | 1 Jan 34 | 3 Dec 34 | 0.92 | 1,908 | |
| | | 1935 | 4 Feb 35 | 30 Jun 35 | 1,664 | 4 Dec 34 | 30 Jun 35 | 0.57 | 2,907 | 2,290 |
| | 49,250 | 1935-38 | 14 Aug 35 | 15 Sep 37 | 1,647 | 1 Jul 35 | 15 Sep 37 | 2.21 | 745 | |
| | | 1938 | 17 Sep 37 | 13 Feb 38 | 324 | 16 Sep 37 | 13 Feb 38 | 0.41 | 783 | 751 |
| 32 × 400 | 54,699 | 1938-40 | 28 Aug 39 | 7 Sep 39 | 38 | 14 Feb 38 | 7 Sep 39 | 1.56 | 24 | 24 |

(Continued)

Note: Dredging volumes are similar to data available in CE Annual Reports; dates of surveys may be in CE Annual Reports or in district files.

* In thousands of cubic yards.

(Sheet 1 of 3)

Table 13 (Continued)

| Channel Dimensions ft | Accumulated New Work | Maintenance Dredging FY | From | To | Volume | Shoaling Interval From | To | Years | Computed Shoaling Rate | Computed Average Shoaling Rate |
|---|---|---|---|---|---|---|---|---|---|---|
| 32 × 400 (Con't) | 59,157 | 1940 | 8 Apr 40 | 17 Jun 40 | 10 | 8 Sep 39 | 17 Jun 40 | 0.77 | 13 | 13 |
| | 60,843 | 1940-42 | 14 Aug 41 | 6 Oct 41 | 318 | 18 Jun 40 | 6 Oct 41 | 1.30 | 244 | 244 |
| | 61,985 | 1942-43 | 15 Apr 42 | 26 Oct 42 | 1,158 | 7 Oct 41 | 26 Oct 42 | 1.05 | 1,098 | |
| | | 1943 | 1 Nov 42 | 25 May 43 | 1,460 | 17 Oct 42 | 25 May 43 | 0.58 | 2,557 | |
| | | 1943-44 | 17 Aug 43 | 15 Oct 43 | 478 | 26 May 43 | 15 Oct 43 | 0.39 | 1,220 | |
| | | 1944-46 | 1 Jul 45 | 3 Apr 46 | 6,515 | 16 Oct 43 | 3 Apr 46 | 2.47 | 2,642 | |
| | | 1946-48 | 4 Nov 47 | 23 Mar 48 | 4,125 | 4 Apr 46 | 23 Mar 48 | 1.97 | 2,094 | |
| | | 1948-49 | 22 May 48 | 13 Aug 48 | 2,193 | 24 Mar 48 | 13 Aug 48 | 0.39 | 5,599 | |
| | | 1949 | 19 Dec 48 | 9 Mar 49 | 1,528 | 14 Aug 48 | 9 Mar 49 | 0.57 | 2,681 | |
| | | 1949 | 12 Apr 49 | 28 Jun 49 | 1,269 | 10 Mar 49 | 28 Jun 49 | 0.30 | 4,175 | |
| | 65,123 | 1949-50 | 5 Dec 49 | 15 May 50 | 1,488 | 29 Jun 49 | 15 May 50 | 0.88 | 1,691 | 1,691 |
| 36 × 400 | 70,196 | 1950-54 | 8 Feb 51 | 2 Sep 53 | 7,533 | 16 May 50 | 2 Sep 53 | 3.30 | 2,282 | 2,282 |
| | 74,181 | 1954 | 21 Dec 53 | 8 Apr 54 | 2,548 | 3 Sep 53 | 8 Apr 54 | 0.60 | 4,266 | |
| | | 1954-56 | 20 May 55 | 4 Aug 55 | 761 | 9 Apr 54 | 4 Aug 55 | 1.32 | 575 | |
| | | 1956 | 27 Oct 55 | 12 Dec 55 | 1,266 | 5 Aug 55 | 12 Dec 55 | 0.36 | 3,554 | |
| | | 1956 | 21 Dec 55 | 30 Jun 56 | 282 | 13 Dec 55 | 30 Jun 56 | 0.55 | 515 | 1,720 |
| | 76,574 | 1956-57 | 30 Aug 56 | 12 Mar 57 | 2,403 | 1 Jul 56 | 12 Mar 57 | 0.70 | 3,439 | 3,439 |
| | 77,128 | 1957-58 | 21 Oct 57 | 22 Dec 57 | 670 | 13 Mar 57 | 22 Dec 57 | 0.78 | 858 | 858 |
| | 78,285 | 1958-59 | 1 Jul 58 | 24 Sep 58 | 2,879 | 23 Dec 57 | 24 Sep 58 | 0.76 | 4,246 | |
| | | 1959 | 22 May 59 | 13 Jun 59 | 47 | 25 Sep 58 | 13 Jun 59 | 0.72 | 65 | 2,211 |
| | 78,359 | 1959-60 | 1 Jul 59 | 13 Oct 59 | 155 | 14 Jun 59 | 13 Oct 59 | 0.33 | 464 | 464 |
| | 79,135 | 1960-61 | 29 Oct 59 | 11 Oct 60 | 1,834 | 14 Oct 59 | 11 Oct 60 | 0.99 | 1,844 | 1,844 |
| | 87,720 | 1961-66 | 1 Jul 61 | 2 Jul 65 | 15,757 | 12 Oct 60 | 2 Jul 65 | 4.72 | 3,336 | 3,336 |

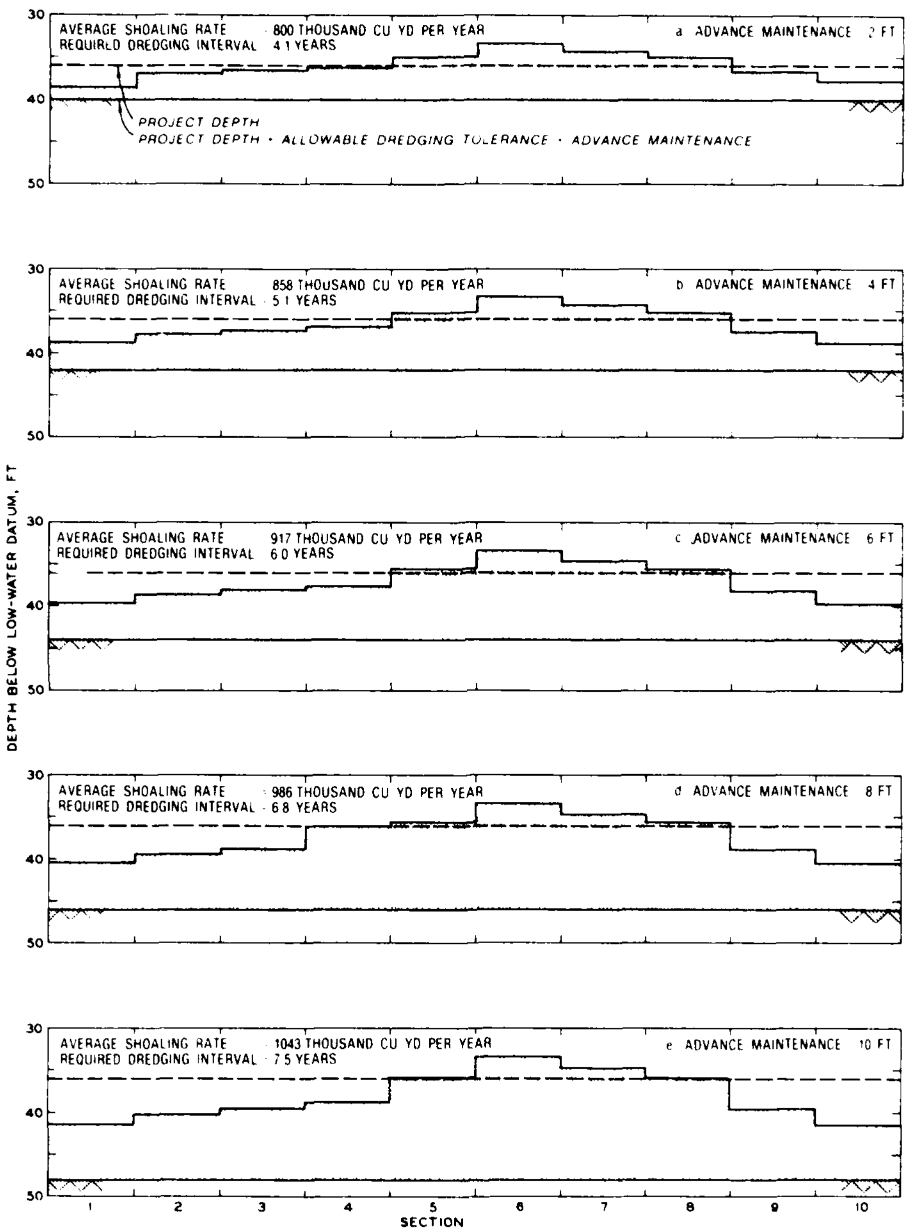
(Continued)

(Sheet 2 of 3)

Table 13 (Concluded)

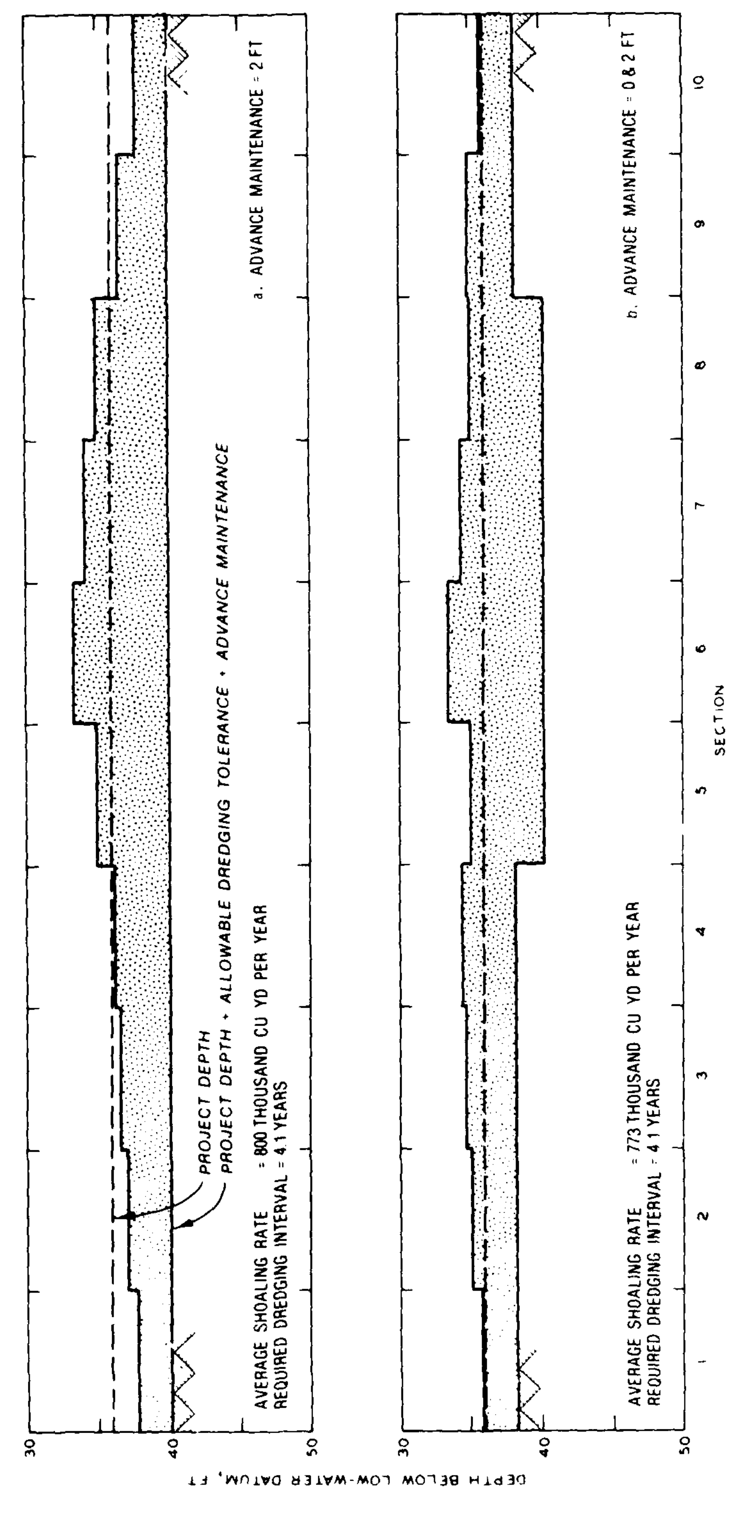
| Channel Dimensions ft | Accumulated New Work | Maintenance Dredging | | | | Shoaling Interval | | | Computed Shoaling Rate | Computed Average Shoaling Rate |
|---|---|---|---|---|---|---|---|---|---|---|
| | | FY | From | To | Volume | From | To | Years | | |
| 40 × 400 | 105,254 | 1966 | 21 Jul 65 | 14 Oct 65 | 156 | 3 Jul 65 | 14 Oct 65 | 0.29 | 547 | 547 |
| | 107,231 | 1966-67 | 27 Apr 66 | 12 Oct 66 | 3,110 | 15 Oct 65 | 12 Oct 66 | 0.99 | 3,127 | |
| | | 1967-69 | 17 Jan 68 | 19 Sep 68 | 5,525 | 13 Oct 66 | 19 Sep 68 | 1.94 | 2,852 | 2,946 |
| | 108,614 | 1969-70 | 7 Aug 69 | 19 Oct 69 | 1,199 | 20 Sep 68 | 19 Oct 69 | 1.08 | 1,108 | |
| | | 1970 | 2 Jan 70 | 23 Jan 70 | 122 | 20 Oct 69 | 23 Jan 70 | 0.26 | 464 | |
| | | 1970-71 | 28 Apr 70 | 20 Jul 70 | 2,632 | 24 Jan 70 | 20 Jul 70 | 0.49 | 5,397 | 2,157 |
| | 108,974 | 1971 | 8 Aug 70 | 3 Feb 71 | 127 | 21 Jul 70 | 3 Feb 71 | 0.54 | 234 | |
| | | 1971-72 | 24 May 71 | 12 Dec 71 | 685 | 4 Feb 71 | 12 Dec 71 | 0.84 | 814 | |
| | | 1972 | 24 Apr 72 | 23 Jun 72 | 1,625 | 13 Dec 71 | 23 Jun 72 | 0.54 | 2,996 | |
| | | 1972-73 | 8 Jul 72 | 24 Aug 72 | 75 | 24 Jun 72 | 24 Aug 72 | 0.17 | 441 | |
| | | 1973-74 | 4 Jan 74 | 15 May 74 | 254 | 25 Aug 72 | 15 May 74 | 1.72 | 147 | |
| | | 1974-75 | 8 Apr 75 | 30 Jun 75 | 2,606 | 16 May 74 | 30 Jun 75 | 1.13 | 2,315 | 1,086 |

(Sheet 3 of 3)




EXAMPLE CHANNEL
SHOALING PATTERNS

UNIFORM ADVANCE MAINTENANCE

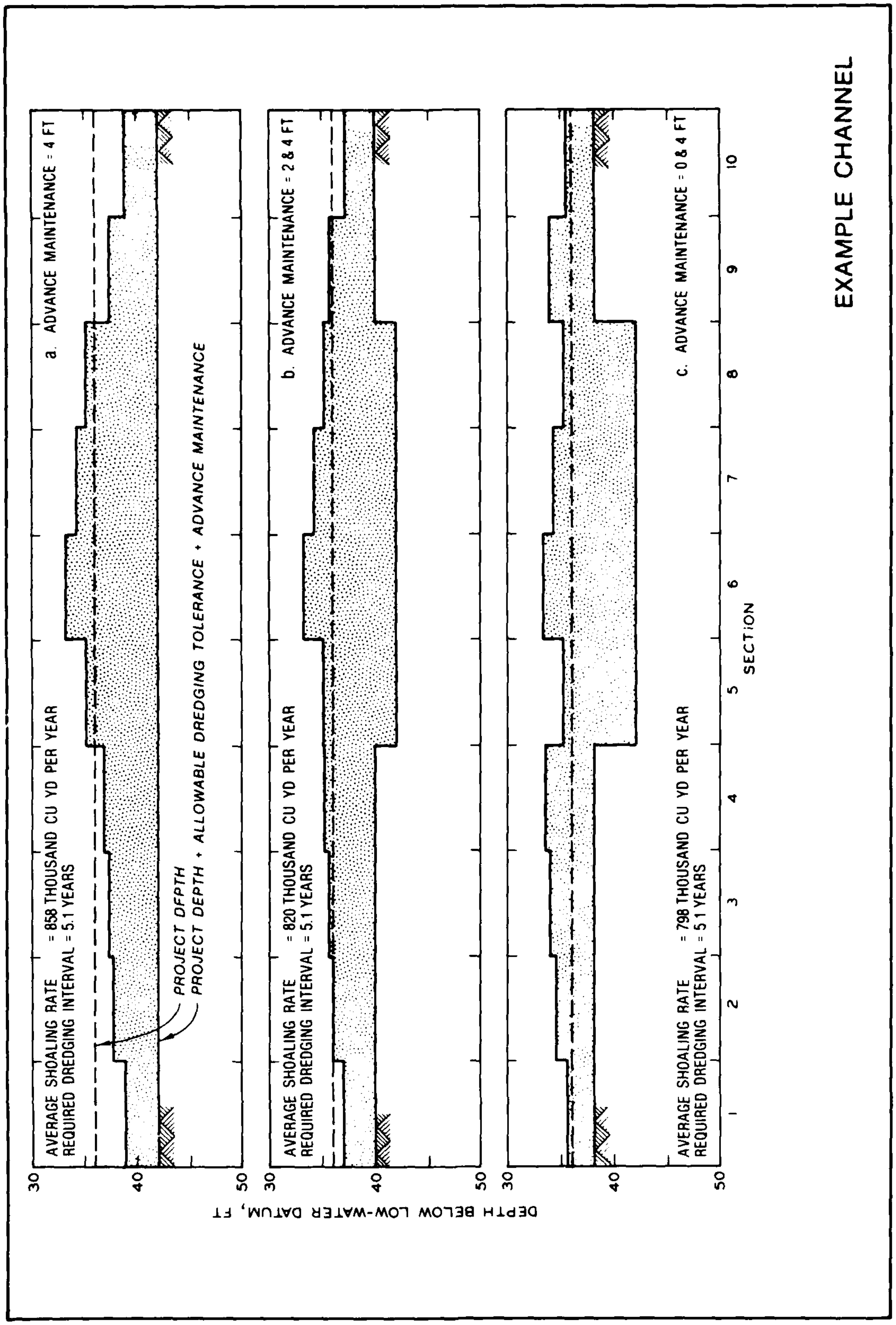



EXAMPLE CHANNEL SHOALING PATTERNS
UNIFORM AND VARIED ADVANCE MAINTENANCE

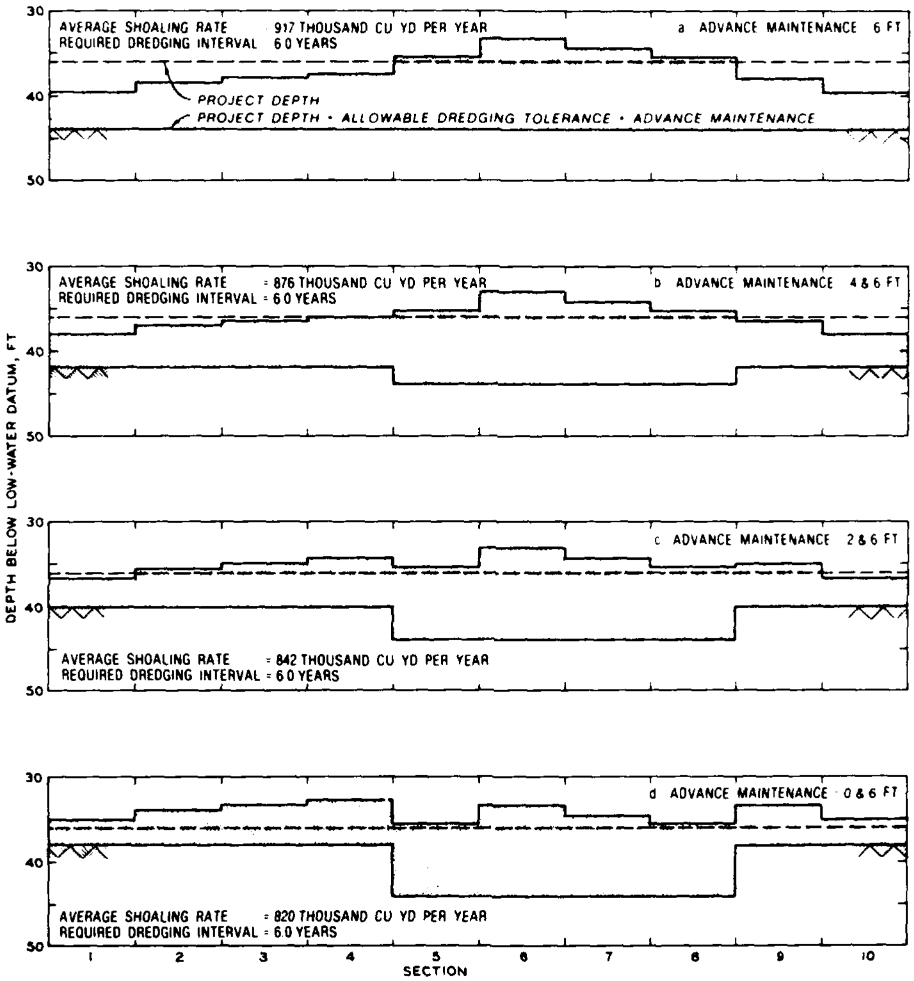
AD-A102 692 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MS F/G 13/2
EFFECTS OF DEPTH ON DREDGING FREQUENCY. REPORT 2. METHODS OF ES--ETC(U)
JUL 81 M J TRAWLE
UNCLASSIFIED WES-TR-H-78-5 NL

2 OF 2
AD A
102892

END
DATE
FILMED
9-81
DTIC

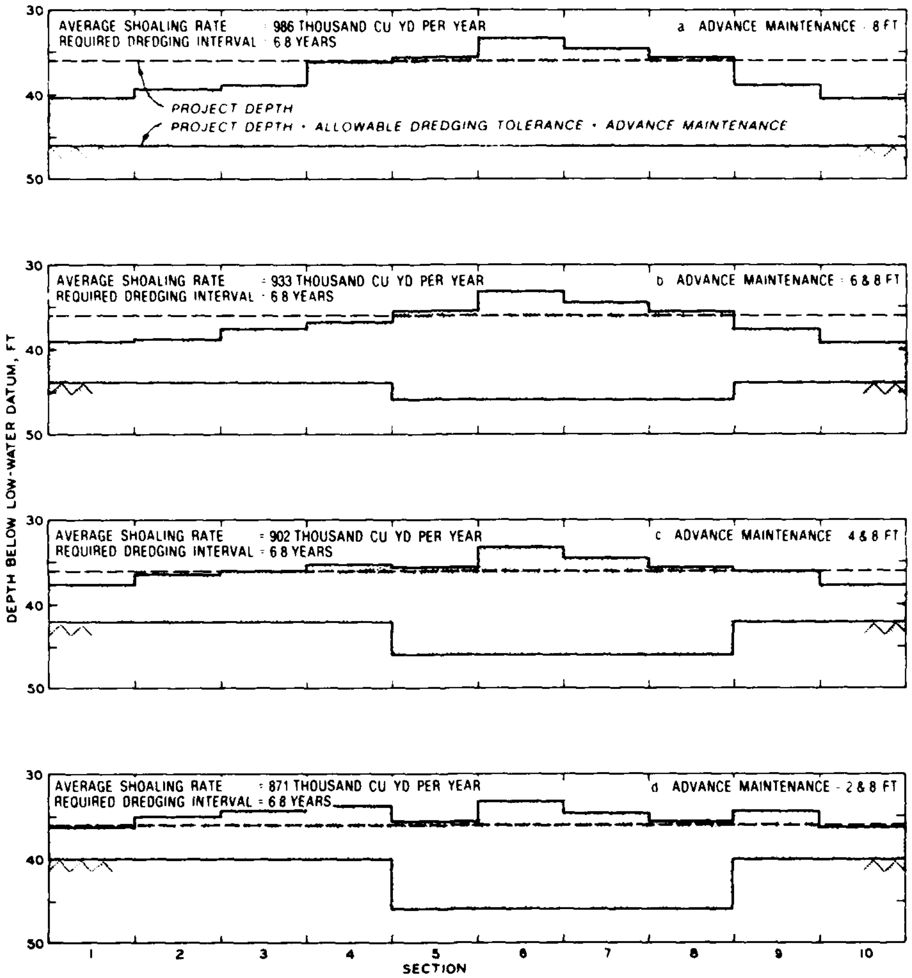


EXAMPLE CHANNEL
AVERAGE SHOALING RATE = 858 THOUSAND CU YD PER YEAR
REQUIRED DREDGING INTERVAL = 5.1 YEARS
a. ADVANCE MAINTENANCE = 4 FT
PROJECT DEPTH
PROJECT DEPTH + ALLOWABLE DREDGING TOLERANCE + ADVANCE MAINTENANCE
AVERAGE SHOALING RATE = 820 THOUSAND CU YD PER YEAR
REQUIRED DREDGING INTERVAL = 5.1 YEARS
b. ADVANCE MAINTENANCE = 2 & 4 FT
AVERAGE SHOALING RATE = 798 THOUSAND CU YD PER YEAR
REQUIRED DREDGING INTERVAL = 5.1 YEARS
c. ADVANCE MAINTENANCE = 0 & 4 FT
DEPTH BELOW LOW-WATER DATUM, FT
SECTION

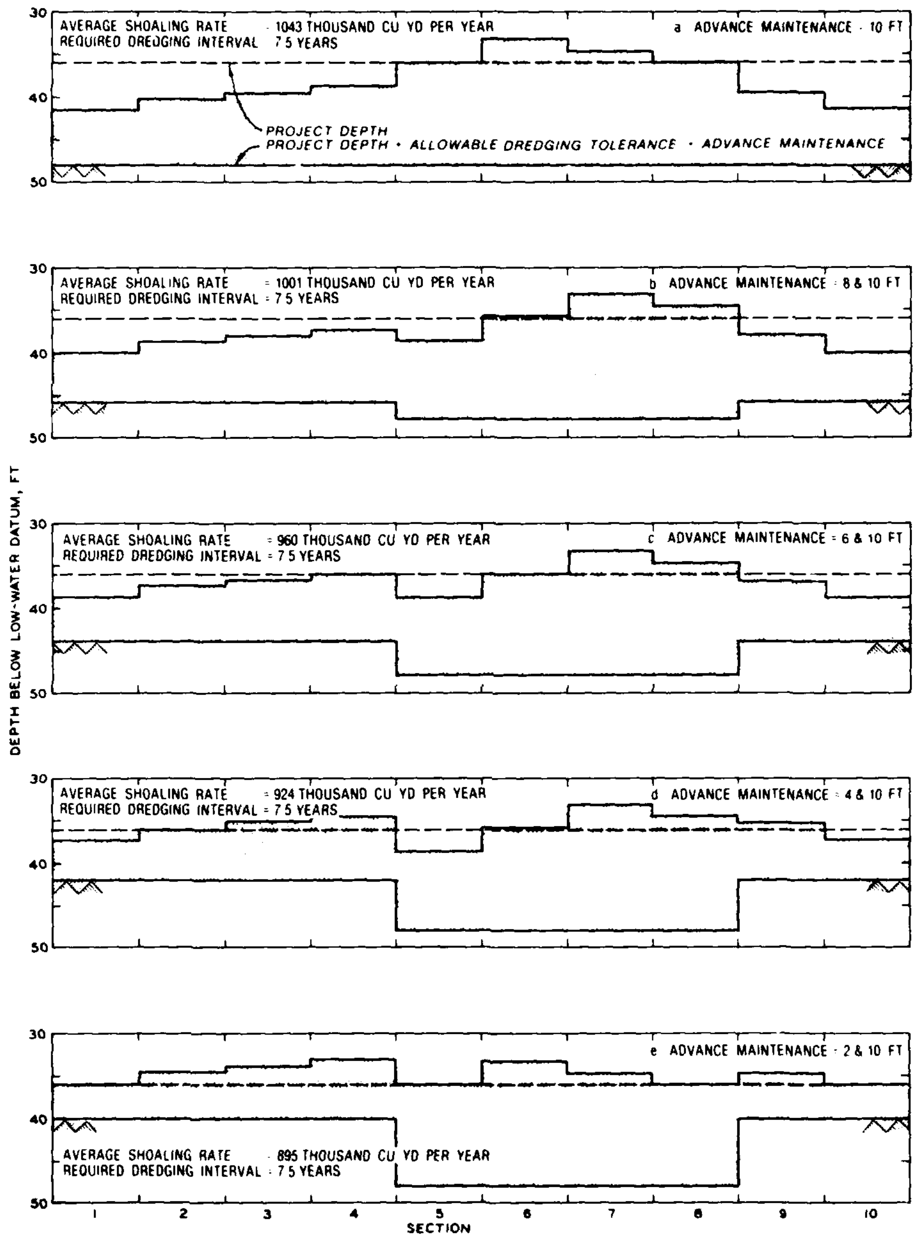



EXAMPLE CHANNEL

6.0-YR DREDGING INTERVAL



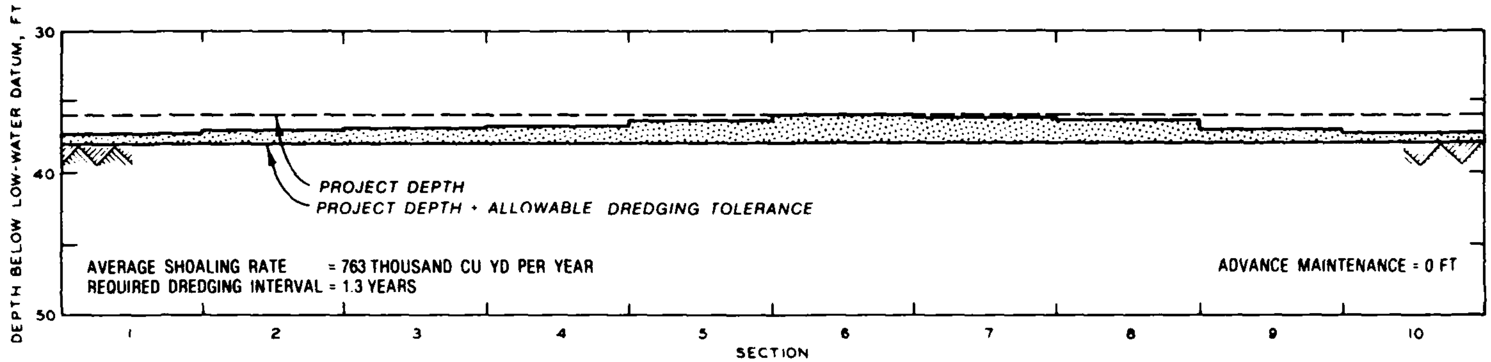

EXAMPLE CHANNEL
6.8-YR DREDGING INTERVAL



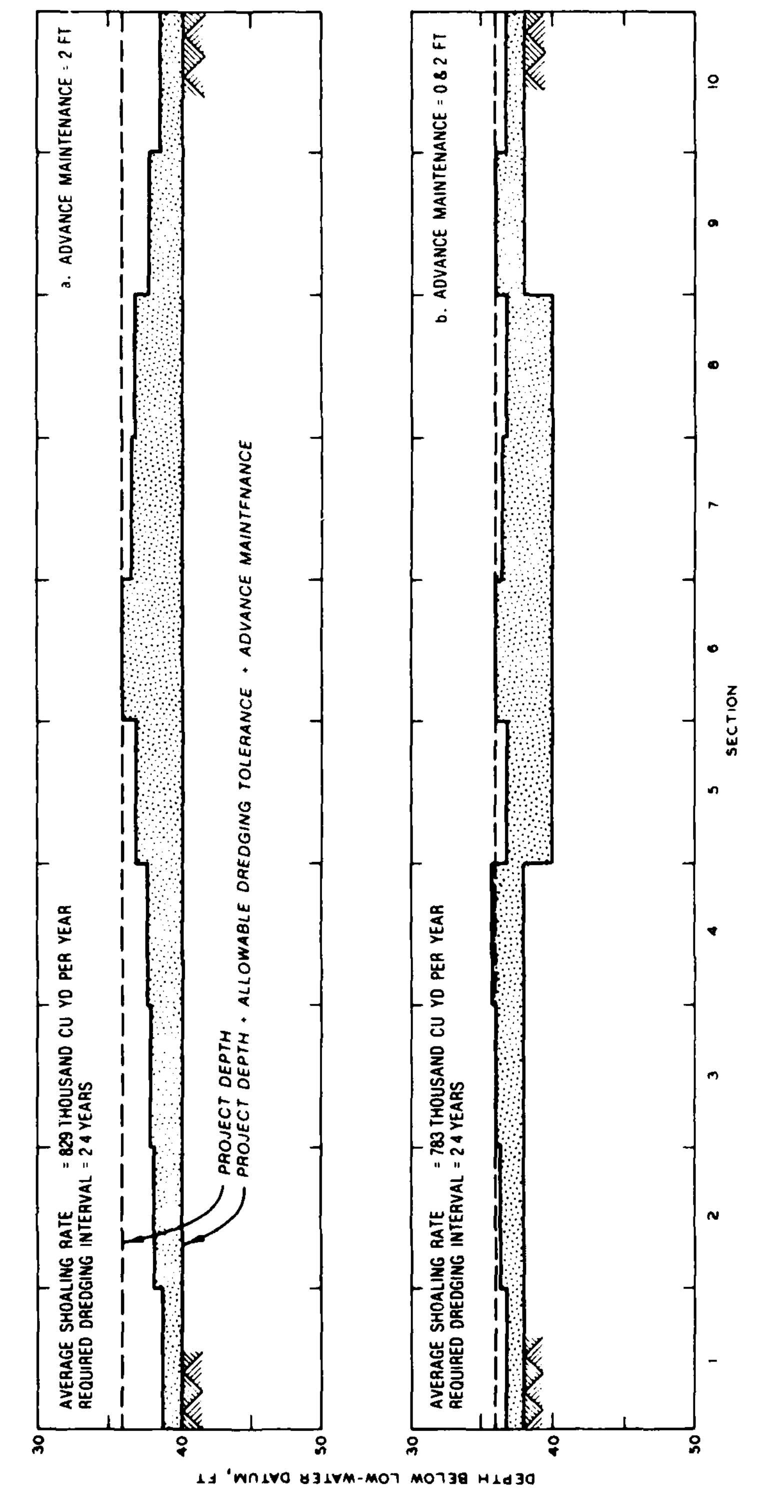

**EXAMPLE CHANNEL**

7.5-YR DREDGING INTERVAL

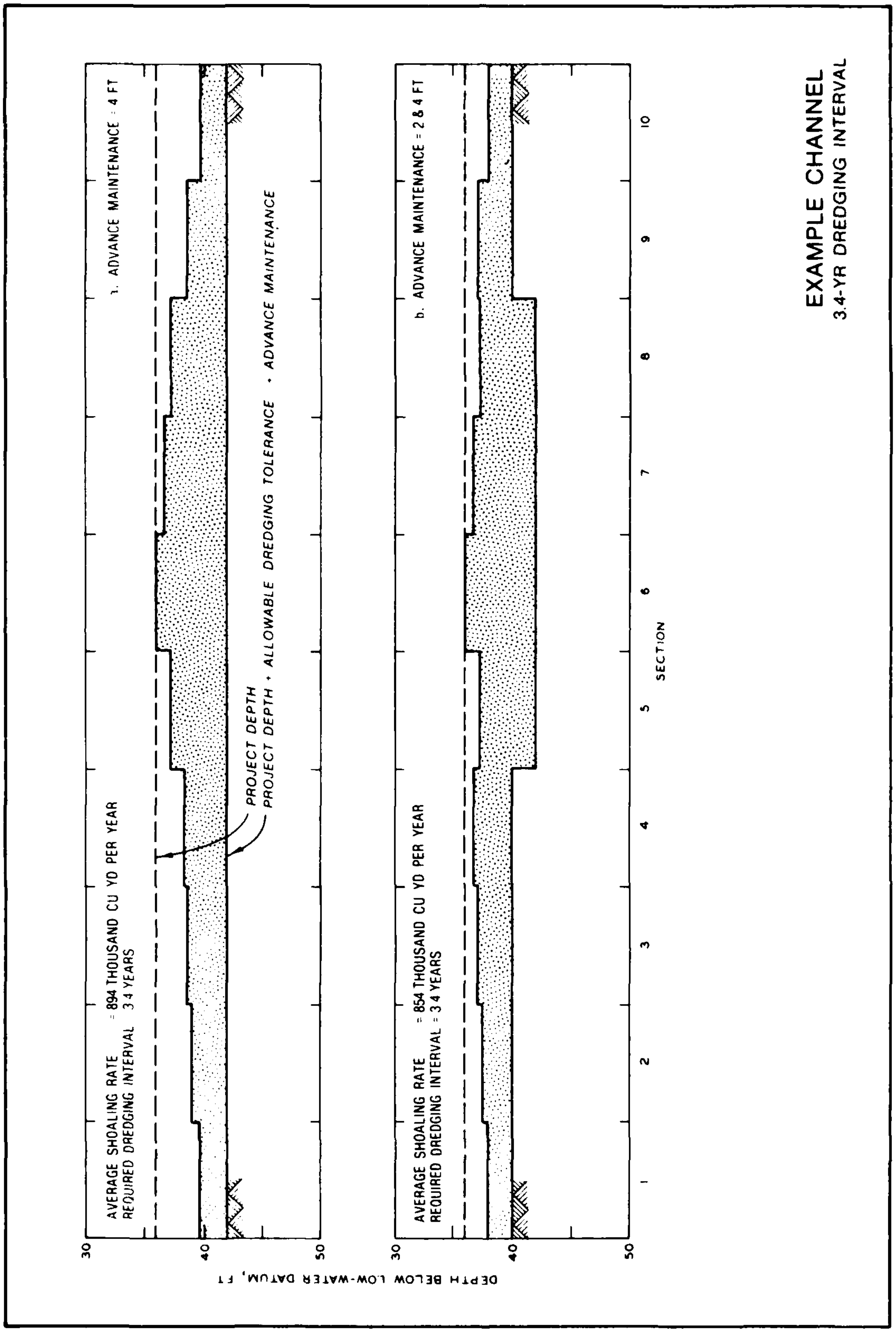
PLATE 6




EXAMPLE CHANNEL
1.3-YR DREDGING INTERVAL

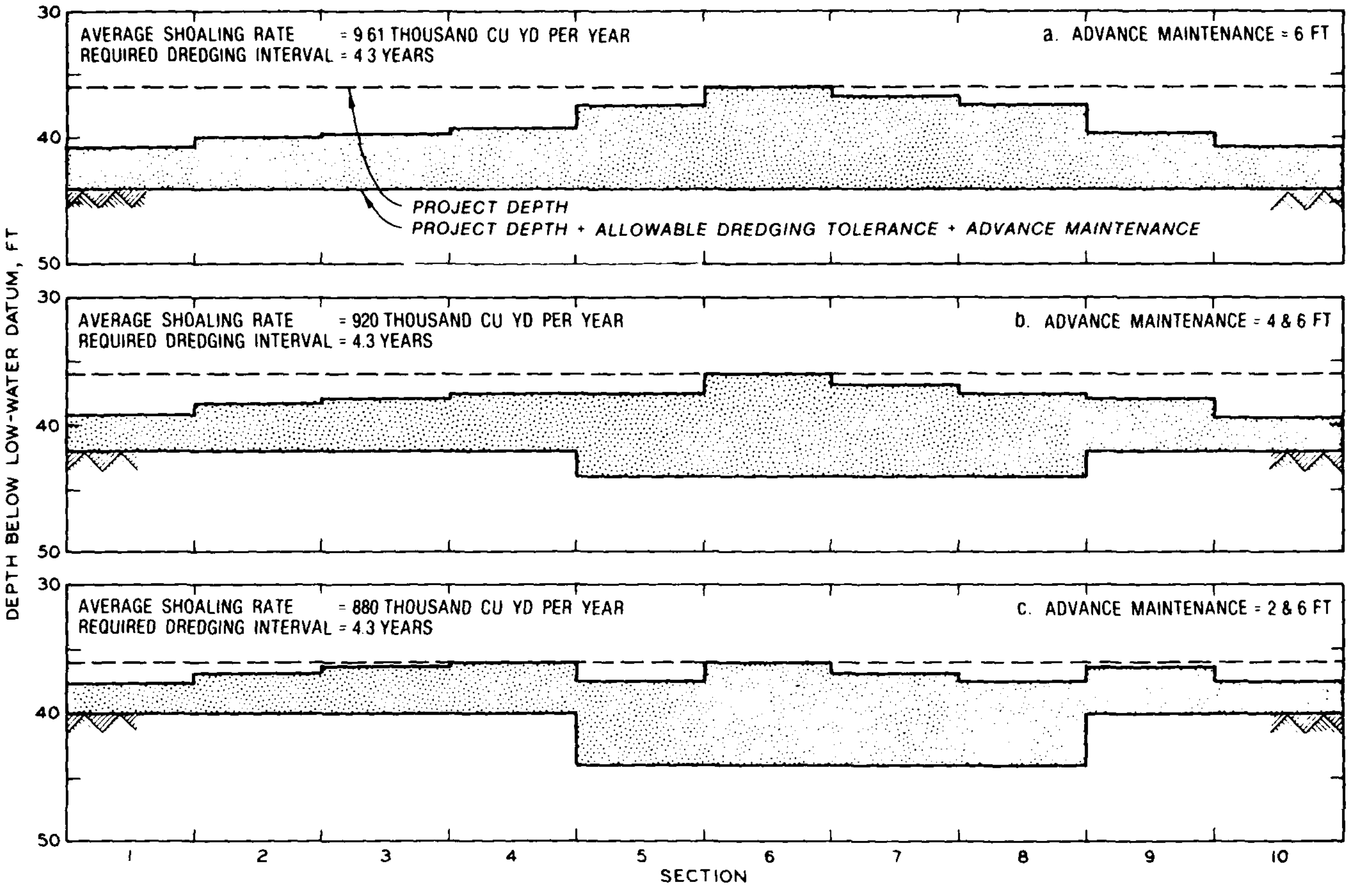



EXAMPLE CHANNEL
2.4-YR DREDGING INTERVAL

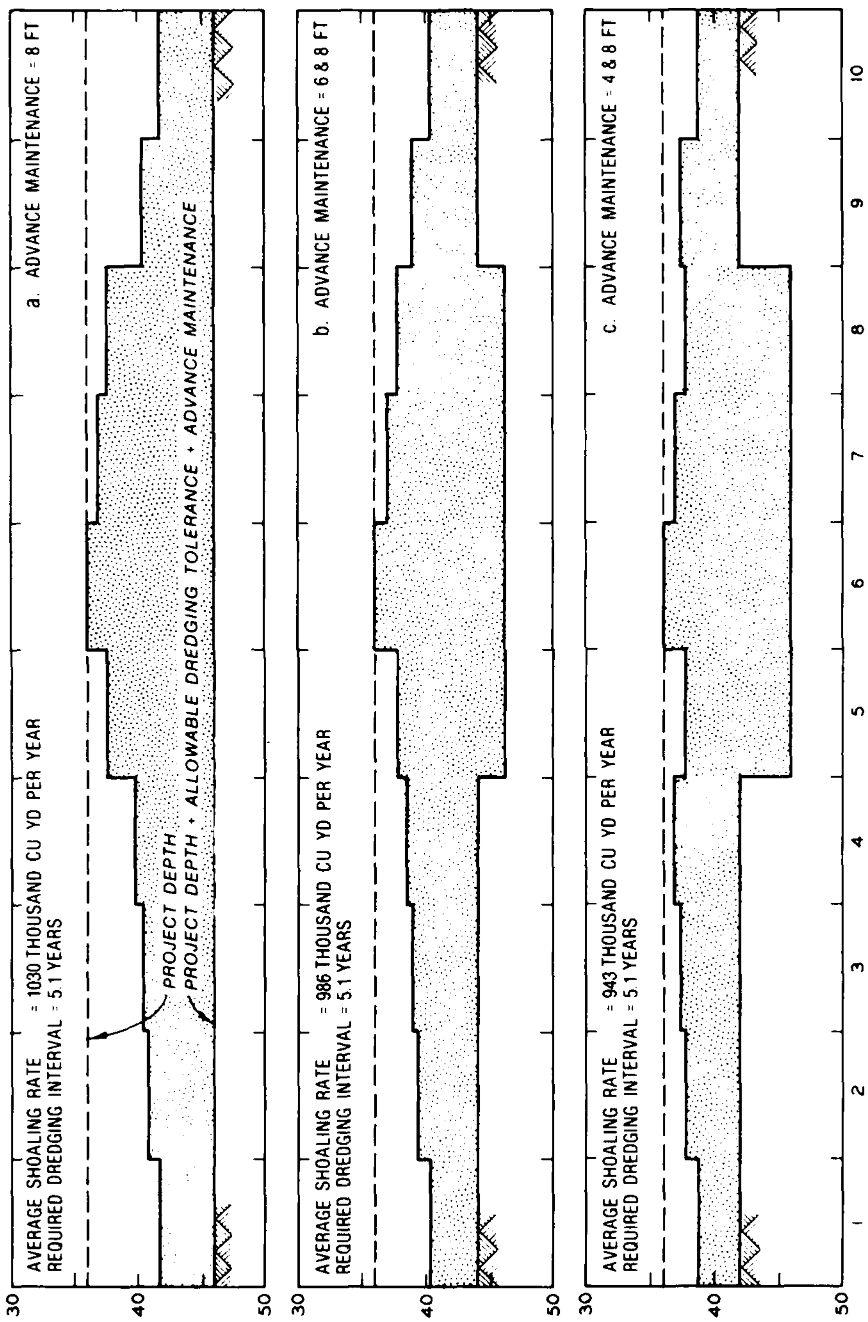



EXAMPLE CHANNEL
3.4-YR DREDGING INTERVAL

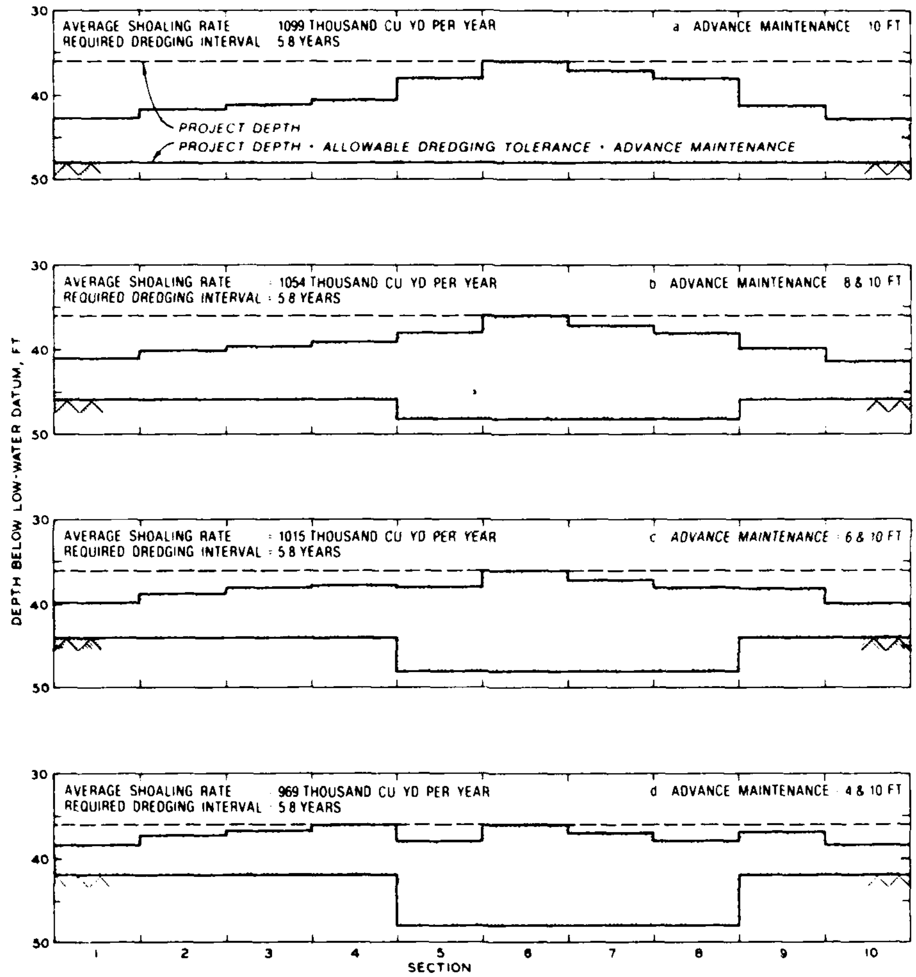
PLATE 9



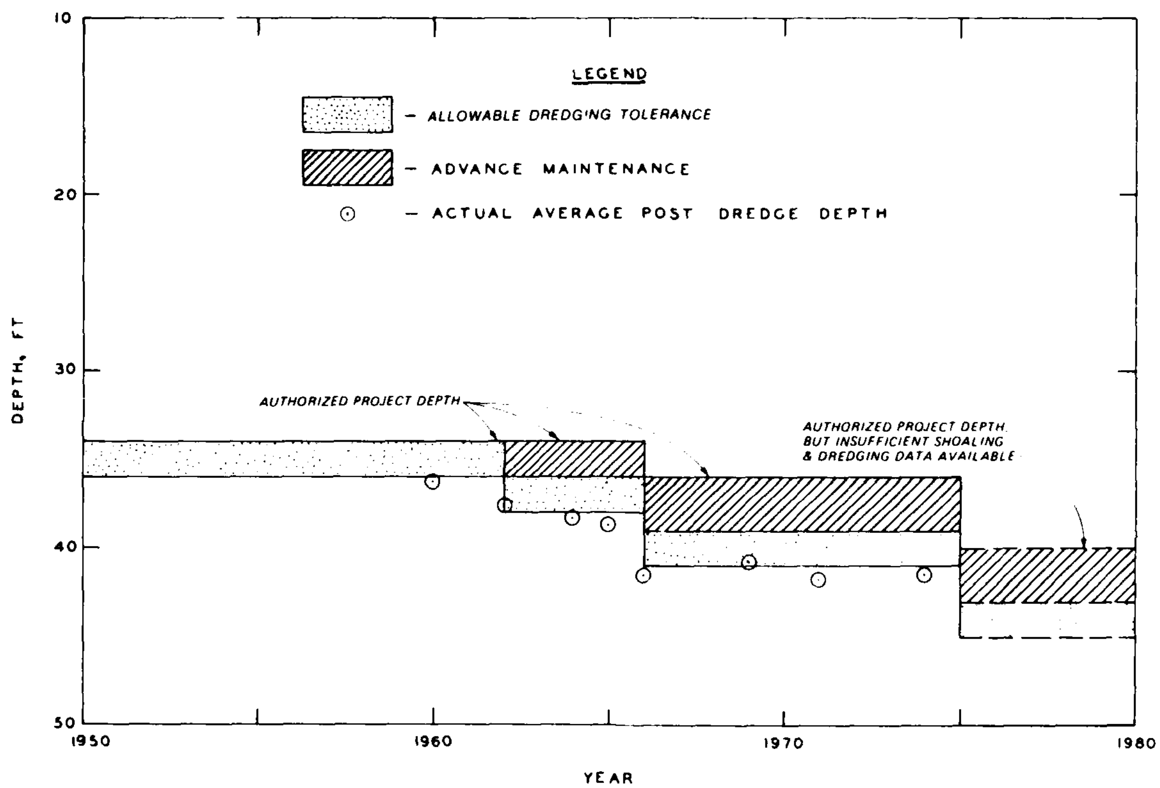

EXAMPLE CHANNEL
4.3-YR DREDGING INTERVAL




EXAMPLE CHANNEL
5.1-YR DREDGING INTERVAL

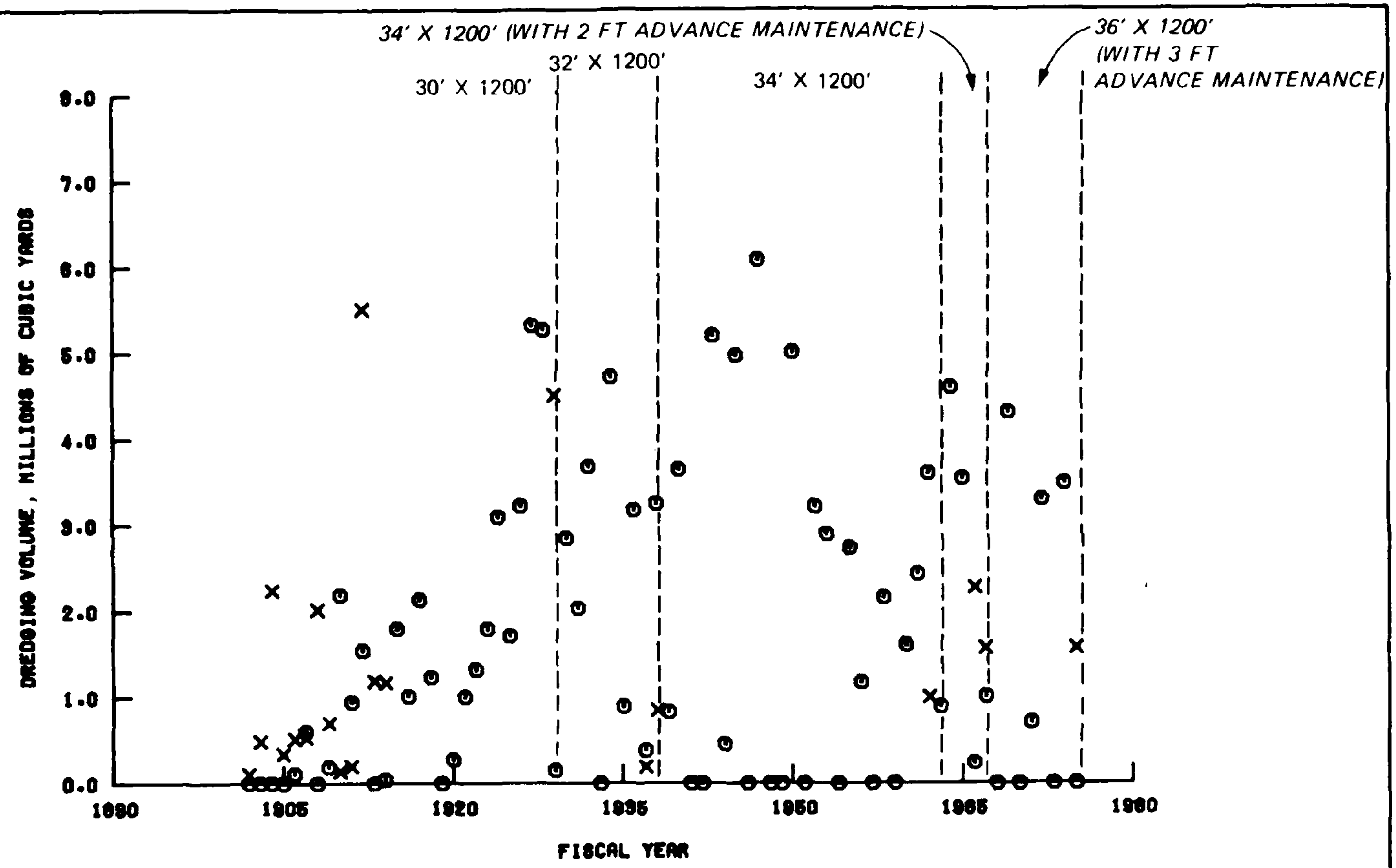



EXAMPLE CHANNEL
5.8-YR DREDGING INTERVAL




GALVESTON CHANNEL
CONTRACT DREDGING DEPTHS

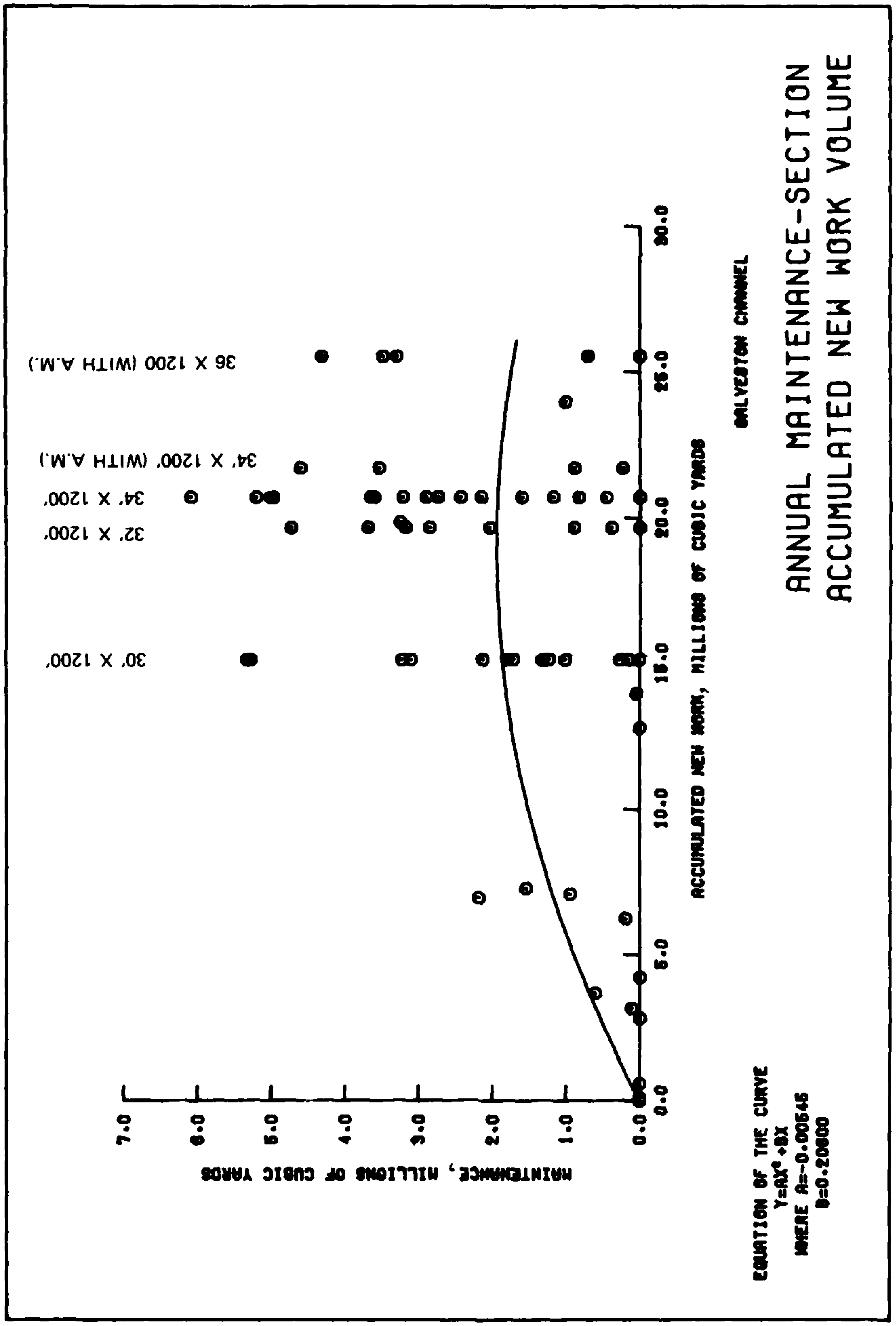
PLATE 14




LEGEND
⊙ MAINTENANCE DREDGING
X NEW WORK DREDGING

GALVESTON CHANNEL

DREDGING HISTORY



ANNUAL MAINTENANCE-SECTION
ACCUMULATED NEW WORK VOLUME
GALVESTON CHANNEL
MAINTENANCE, MILLIONS OF CUBIC YARDS
ACCUMULATED NEW WORK, MILLIONS OF CUBIC YARDS
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
0.0
5.0
10.0
15.0
20.0
25.0
30.0
30' X 1200'
32' X 1200'
34' X 1200'
34' X 1200' (WITH A.M.)
36 X 1200 (WITH A.M.)
EQUATION OF THE CURVE
Y=AX²+BX
WHERE A=-0.00646
B=0.20600


PLATE 15

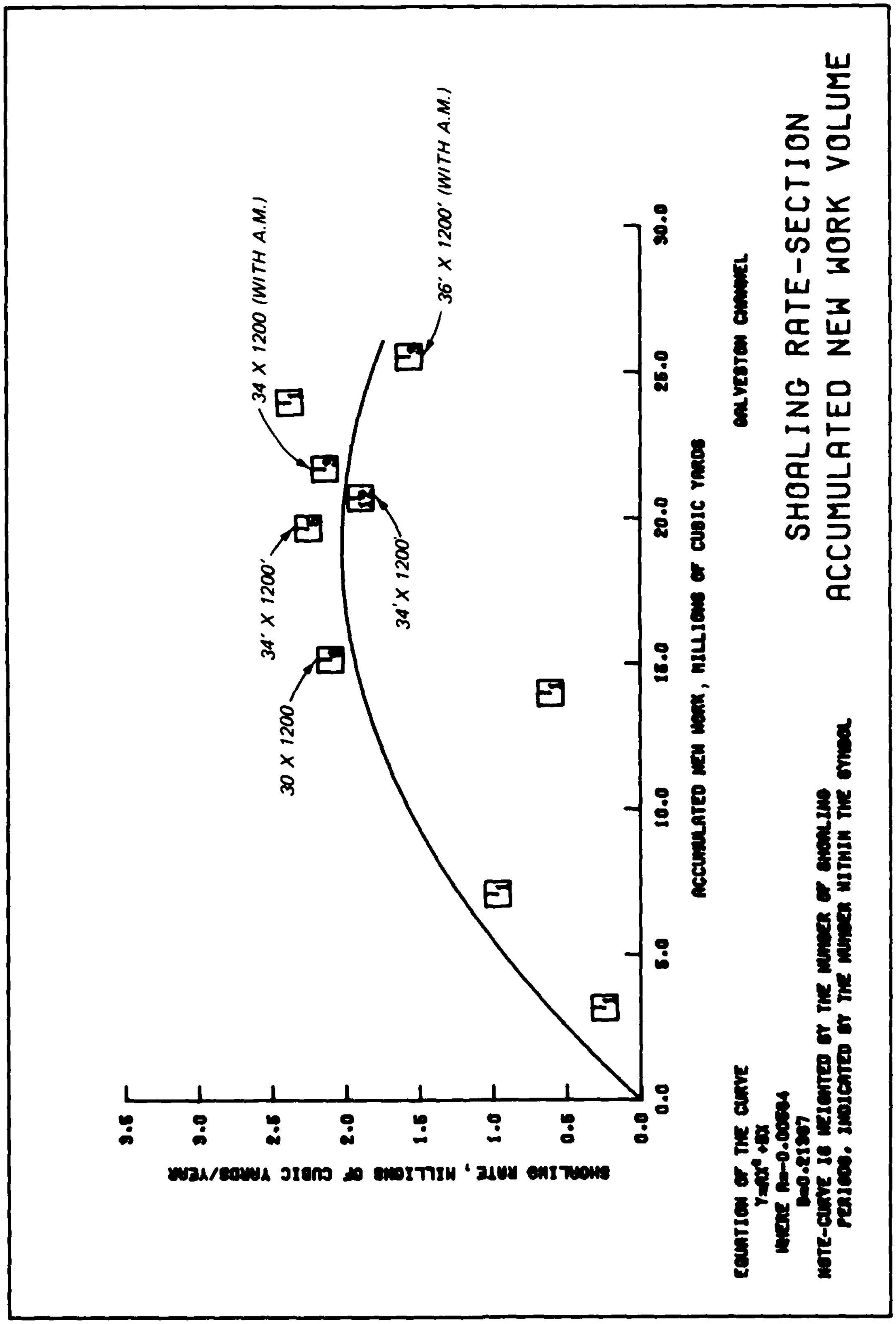
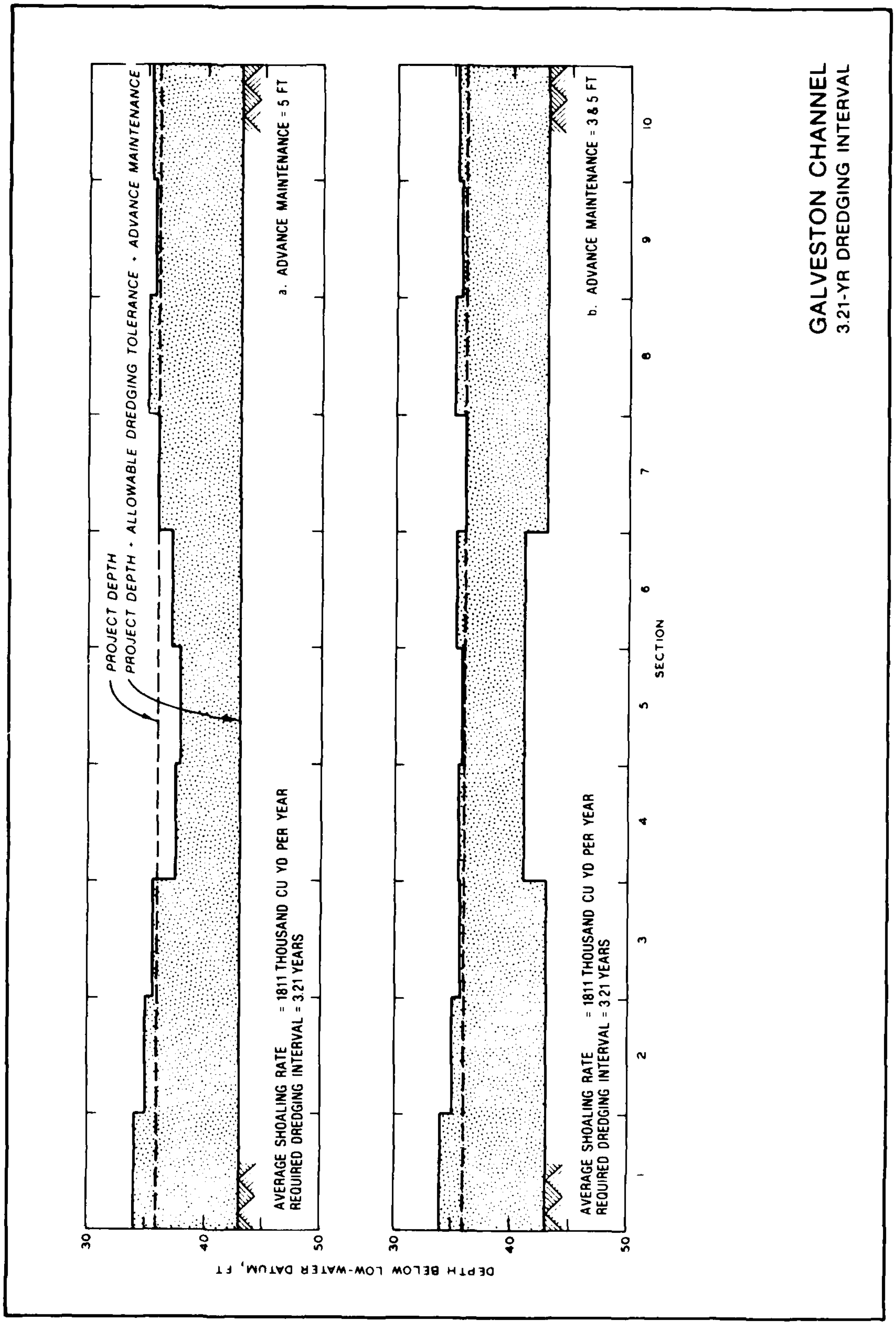
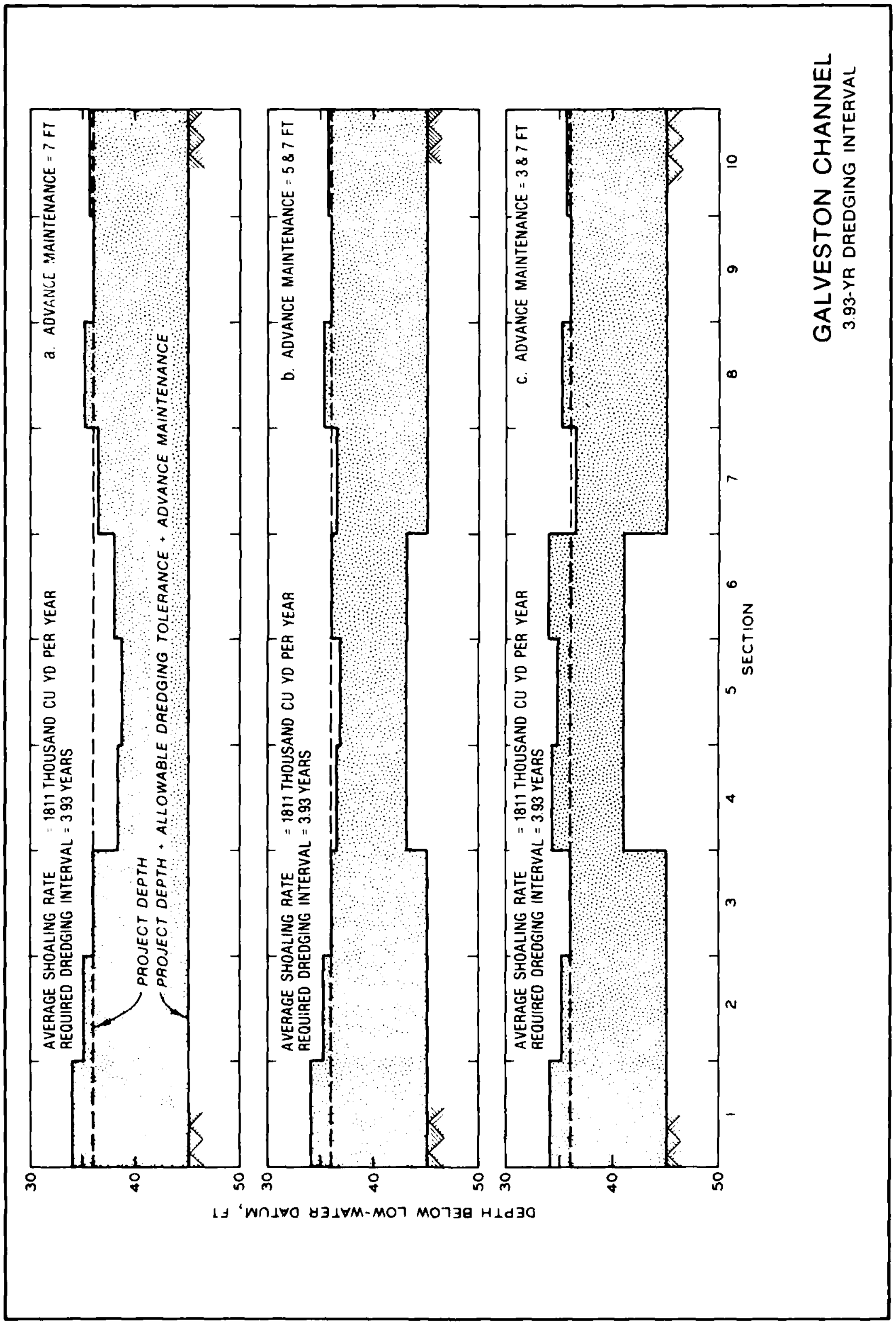

SHOALING RATE-SECTION
ACCUMULATED NEW WORK VOLUME
GALVESTON CHANNEL
SHOALING RATE, MILLIONS OF CUBIC YARDS/YEAR
ACCUMULATED NEW WORK, MILLIONS OF CUBIC YARDS
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
0.0
5.0
10.0
15.0
20.0
25.0
30.0
30 X 1200
34' X 1200'
34 X 1200 (WITH A.M.)
34' X 1200'
36' X 1200' (WITH A.M.)
EQUATION OF THE CURVE
Y=AX²+BX
WHERE A=-0.00584
B=0.21987
NOTE-CURVE IS WEIGHTED BY THE NUMBER OF SHOALING
PERIODS, INDICATED BY THE NUMBER WITHIN THE SYMBOL

PLATE 16

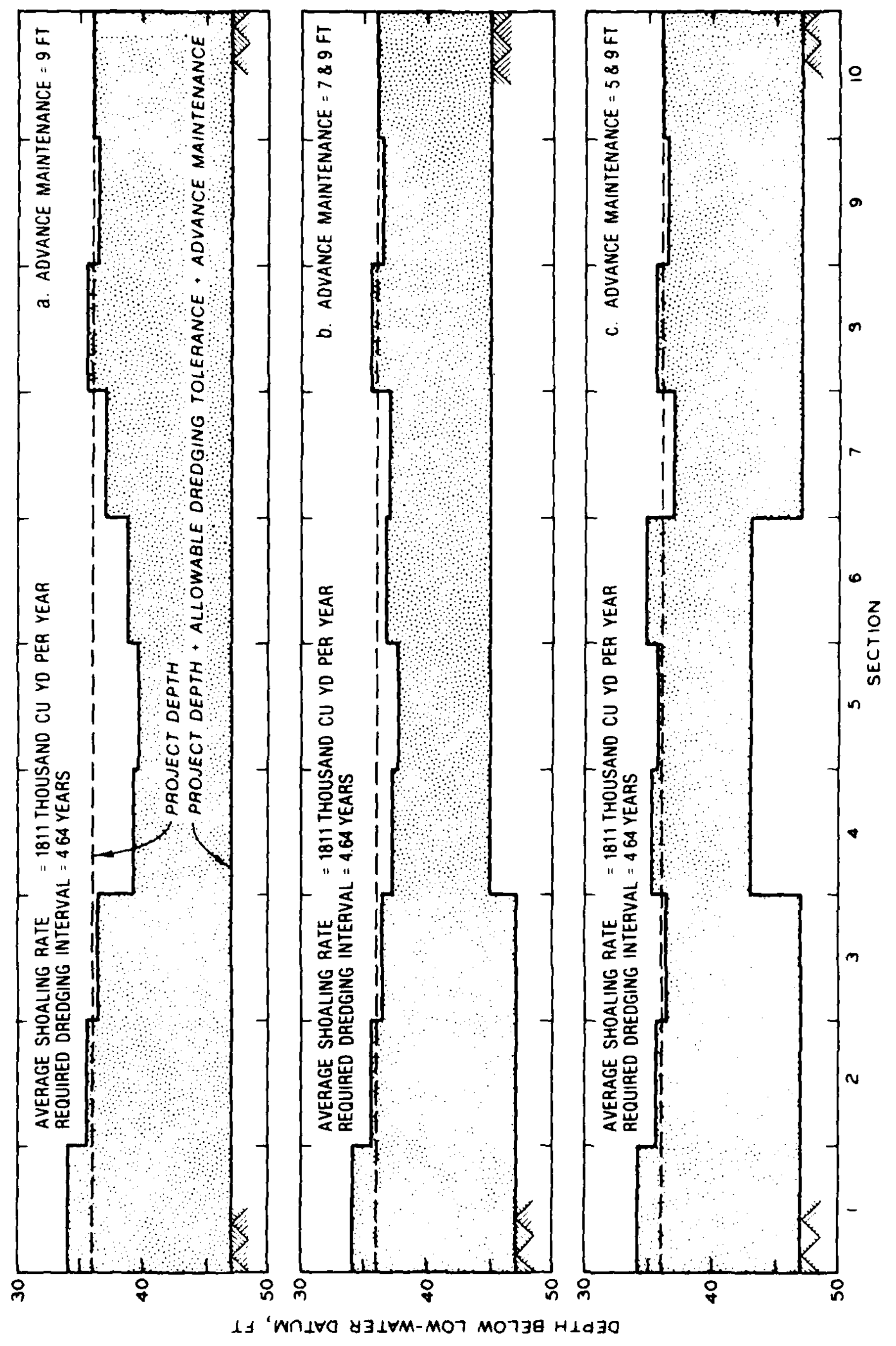

GALVESTON CHANNEL
3.21-YR DREDGING INTERVAL
PROJECT DEPTH
PROJECT DEPTH + ALLOWABLE DREDGING TOLERANCE + ADVANCE MAINTENANCE
AVERAGE SHOALING RATE = 1811 THOUSAND CU YD PER YEAR
REQUIRED DREDGING INTERVAL = 3.21 YEARS
a. ADVANCE MAINTENANCE = 5 FT
AVERAGE SHOALING RATE = 1811 THOUSAND CU YD PER YEAR
REQUIRED DREDGING INTERVAL = 3.21 YEARS
b. ADVANCE MAINTENANCE = 3 & 5 FT
DEPTH BELOW LOW-WATER DATUM, FT
30
40
50
SECTION
1
2
3
4
5
6
7
8
9
10



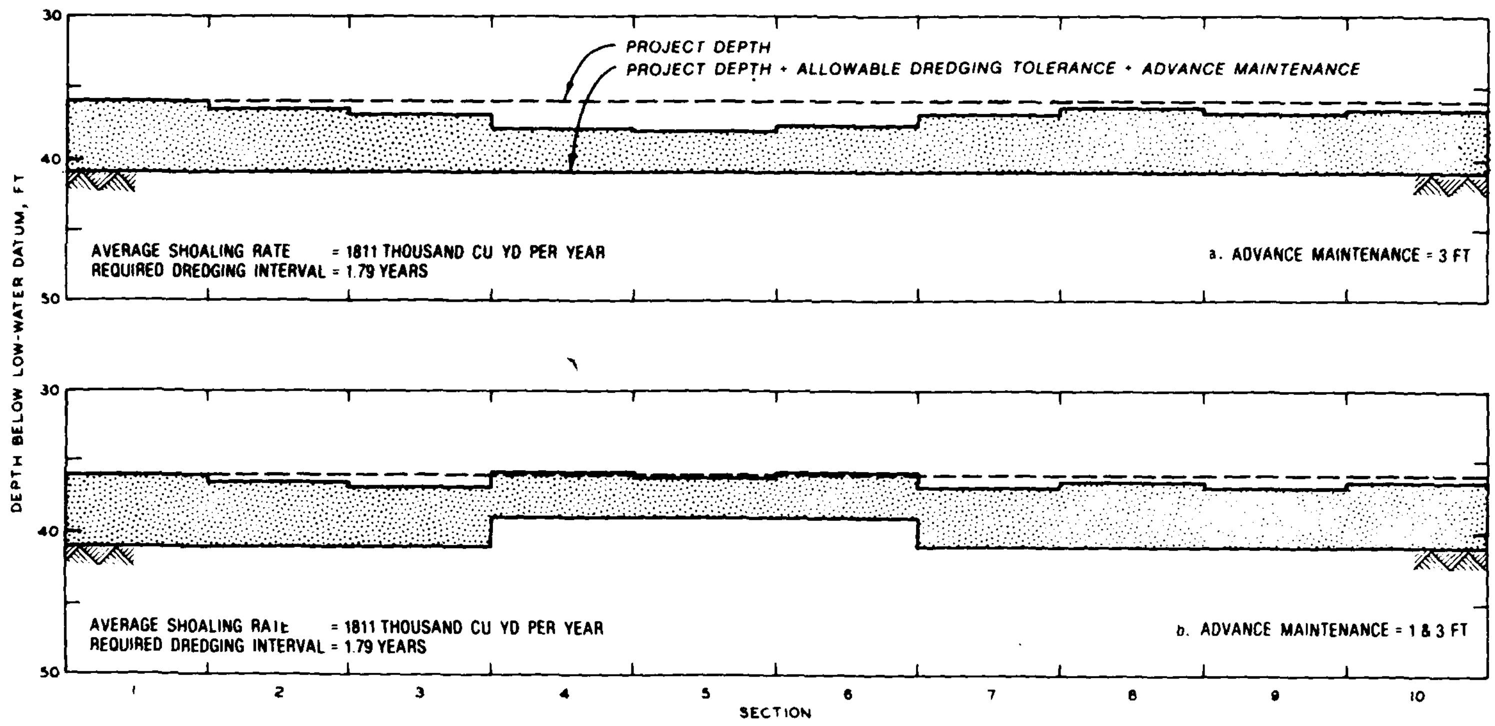

GALVESTON CHANNEL

3.93-YR DREDGING INTERVAL

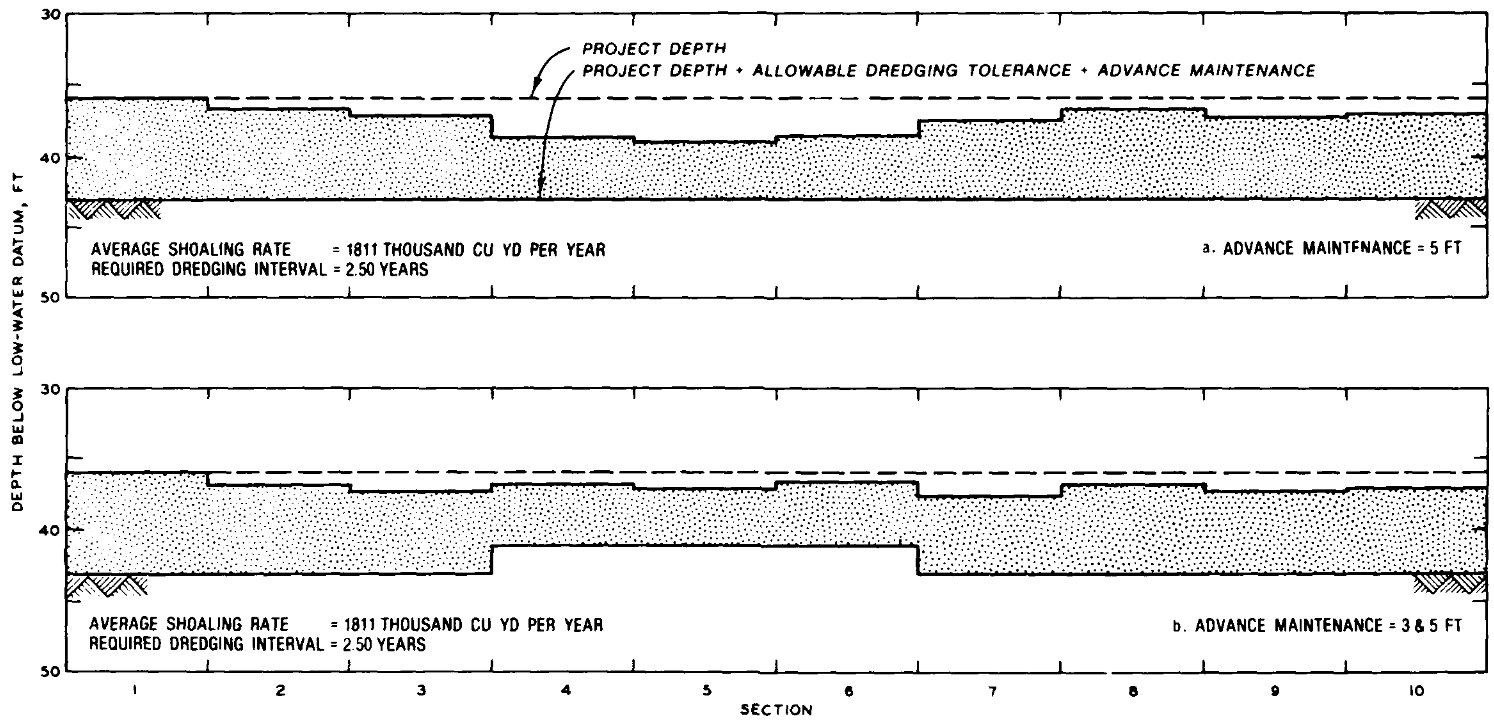
PLATE 18



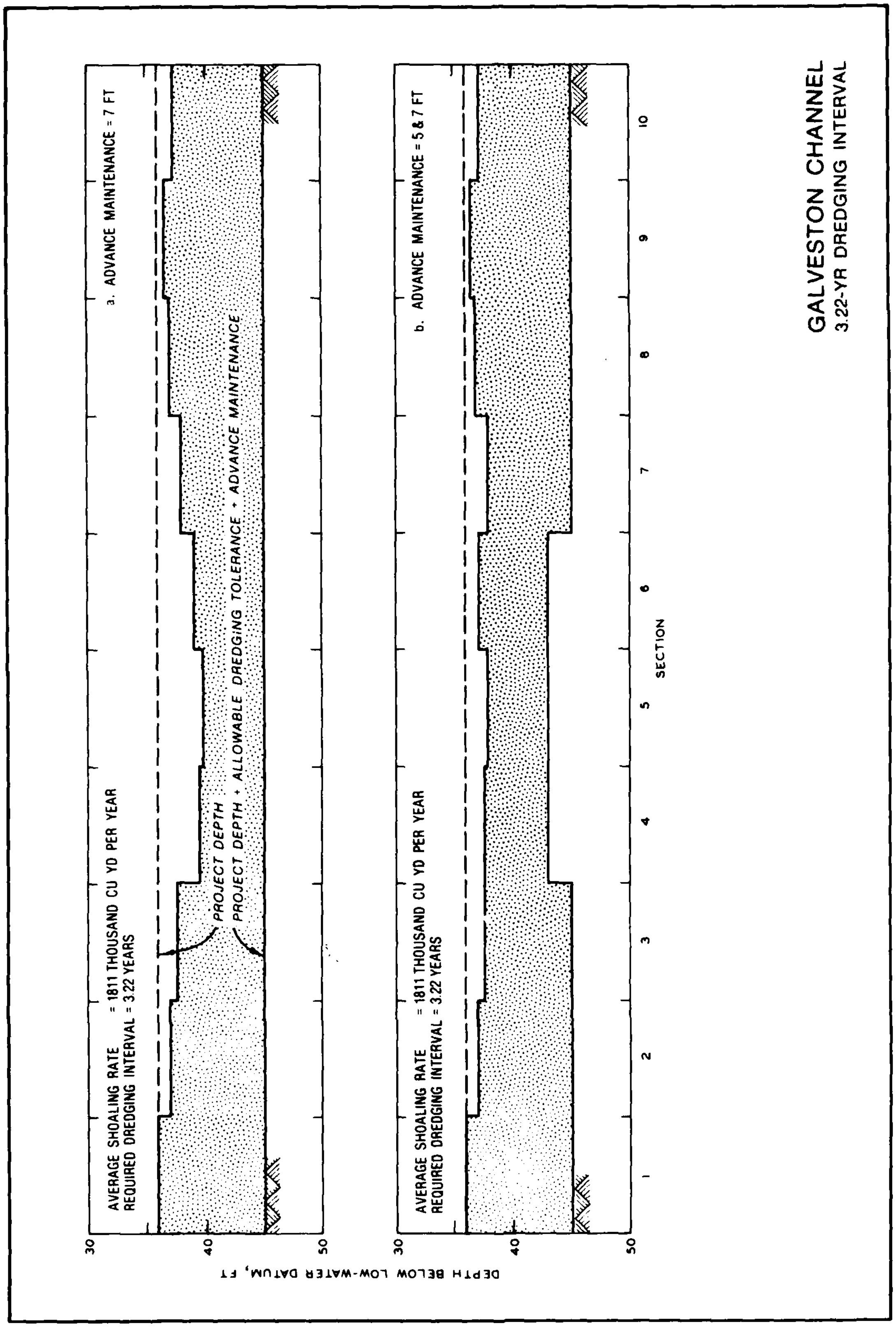

GALVESTON CHANNEL
4.64-YR DREDGING INTERVAL




GALVESTON CHANNEL
1.79-YR DREDGING INTERVAL

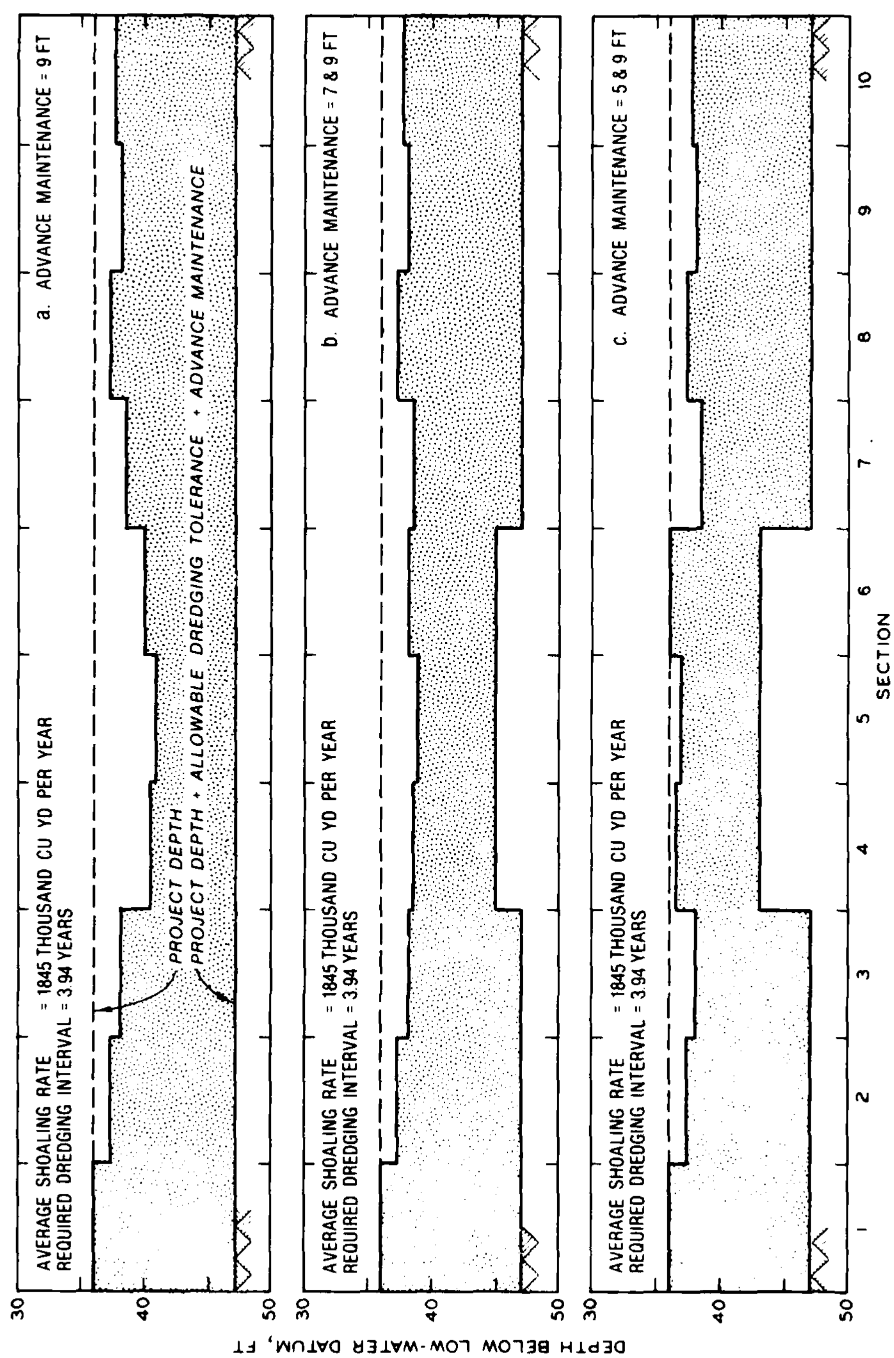



GALVESTON CHANNEL
2.50-YR DREDGING INTERVAL




GALVESTON CHANNEL
3.22-YR DREDGING INTERVAL

PLATE 22




GALVESTON CHANNEL
3.94-YR DREDGING INTERVAL

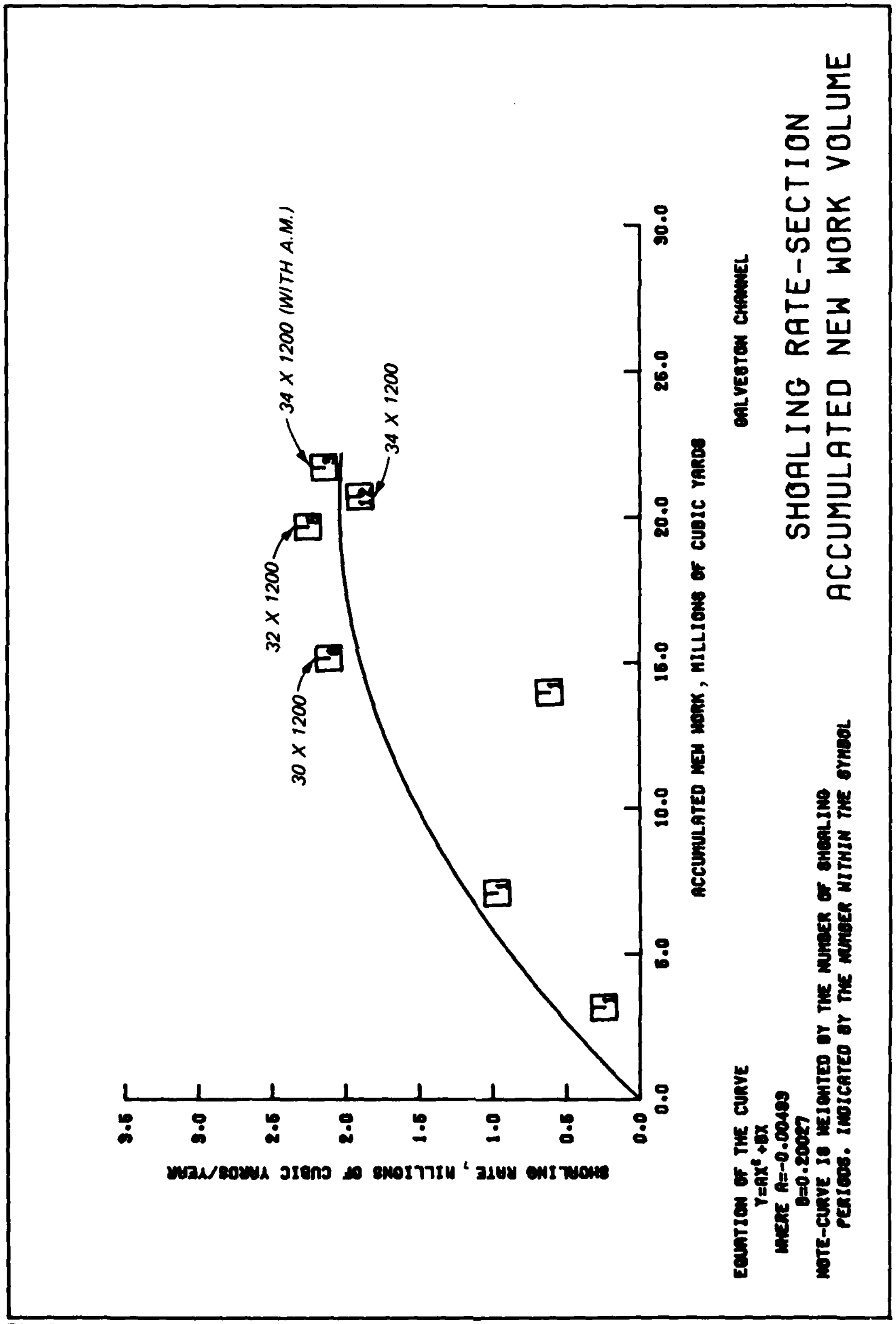
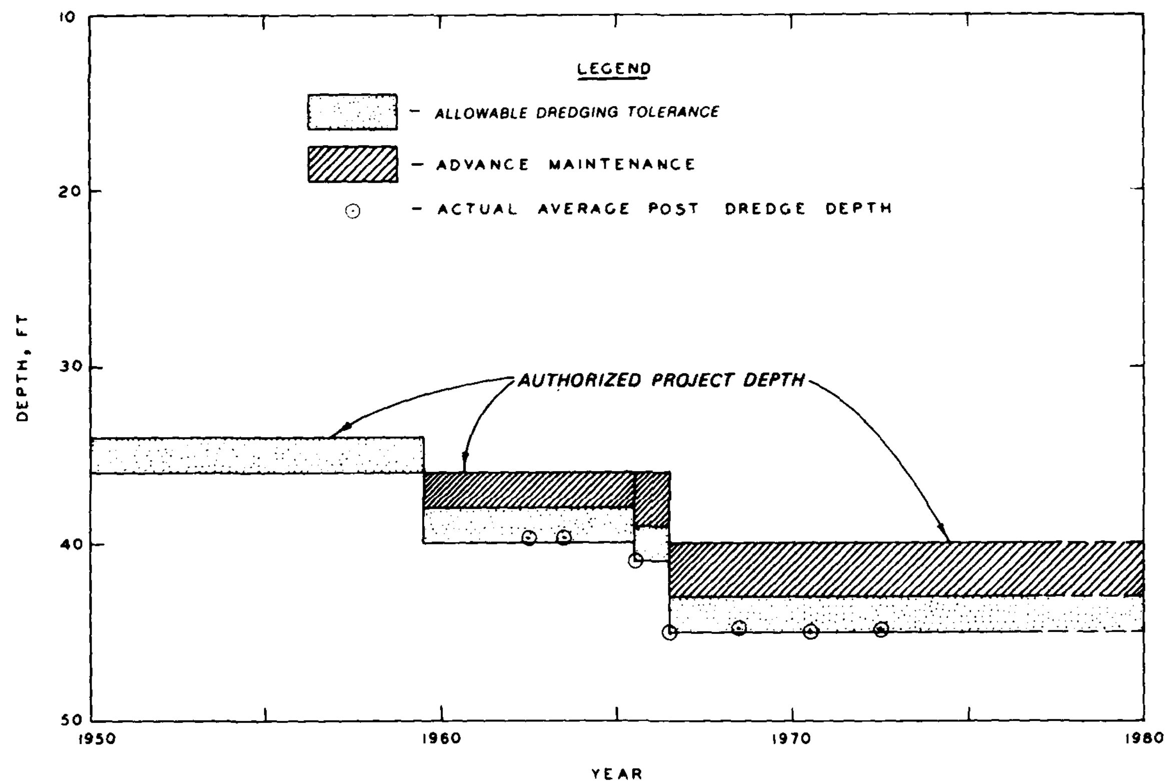

SHOALING RATE-SECTION
ACCUMULATED NEW WORK VOLUME
GALVESTON CHANNEL
SHOALING RATE, MILLIONS OF CUBIC YARDS/YEAR
ACCUMULATED NEW WORK, MILLIONS OF CUBIC YARDS
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
0.0
5.0
10.0
15.0
20.0
25.0
30.0
30 X 1200
32 X 1200
34 X 1200 (WITH A.M.)
34 X 1200
EQUATION OF THE CURVE
Y=AX²+BX
WHERE A=-0.00489
B=0.20027
NOTE-CURVE IS WEIGHTED BY THE NUMBER OF SHOALING
PERIODS. INDICATED BY THE NUMBER WITHIN THE SYMBOL

PLATE 24




TEXAS CITY CHANNEL
CONTRACT DREDGING DEPTHS

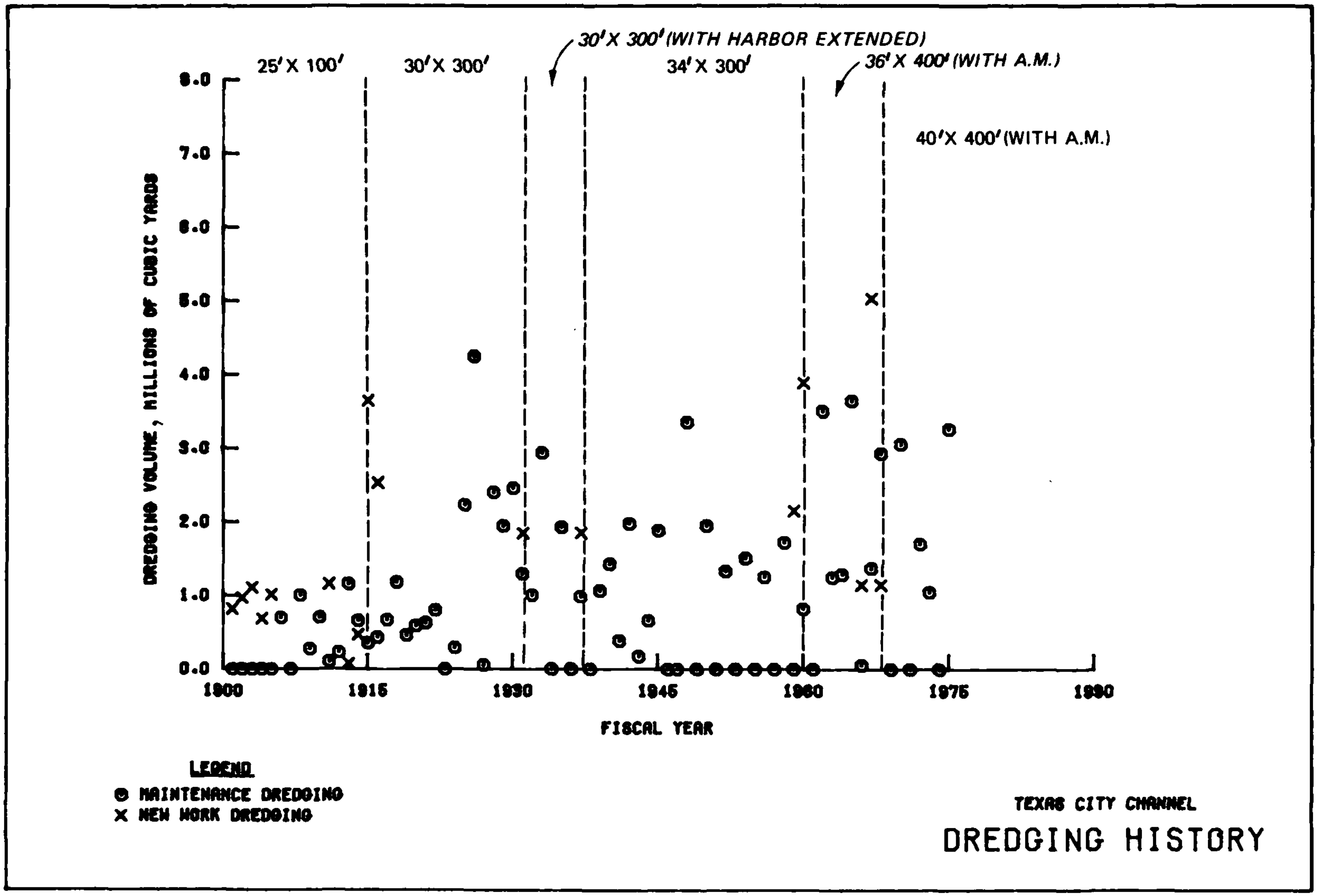

25′ X 100′
30′ X 300′
30′ X 300′ (WITH HARBOR EXTENDED)
34′ X 300′
36′ X 400′ (WITH A.M.)
40′ X 400′ (WITH A.M.)
DREDGING VOLUME, MILLIONS OF CUBIC YARDS
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
1900
1915
1930
1945
1960
1975
1990
FISCAL YEAR
LEGEND
MAINTENANCE DREDGING
X NEW WORK DREDGING
TEXAS CITY CHANNEL
DREDGING HISTORY

PLATE 26

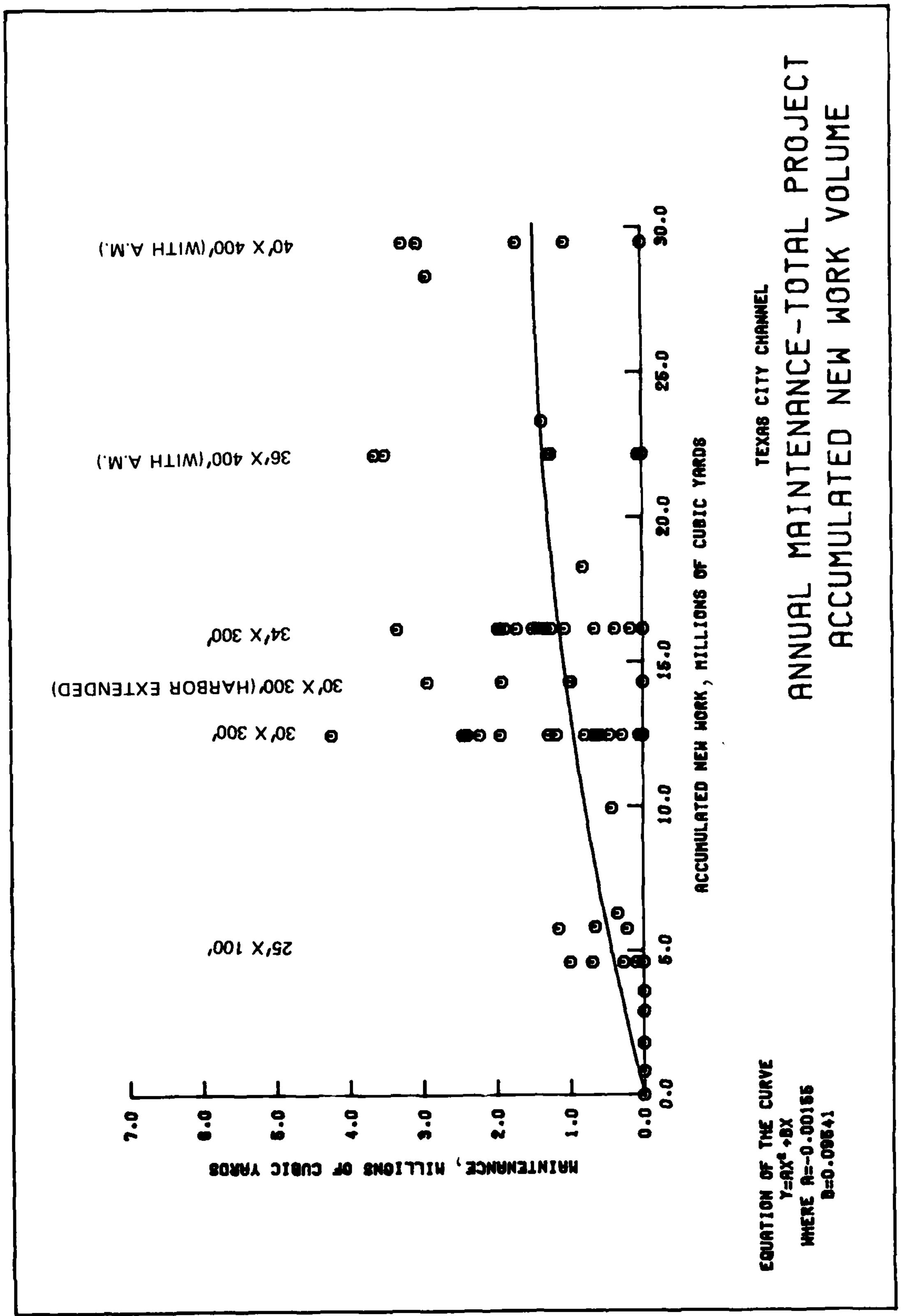
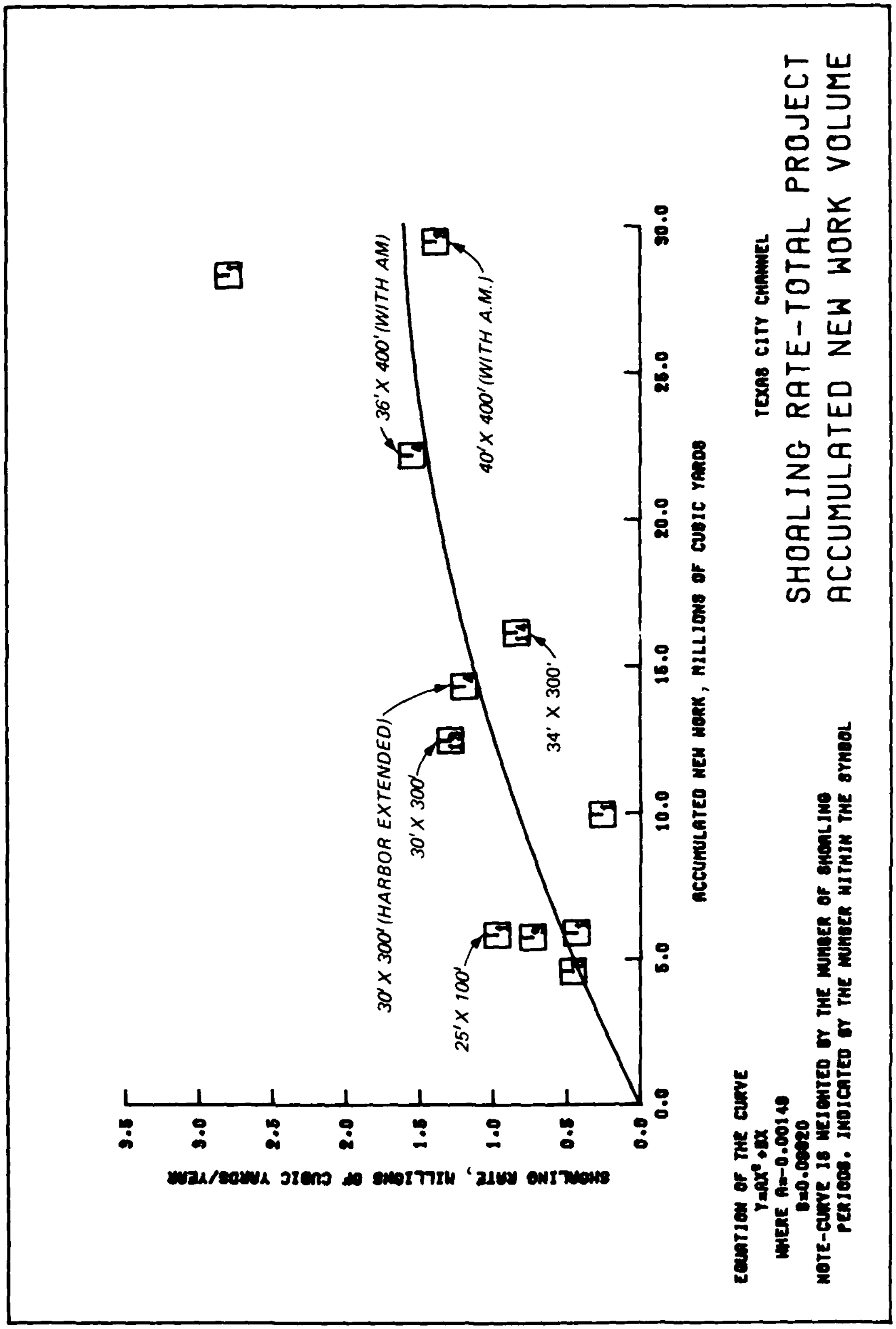

ANNUAL MAINTENANCE-TOTAL PROJECT
ACCUMULATED NEW WORK VOLUME
TEXAS CITY CHANNEL
MAINTENANCE, MILLIONS OF CUBIC YARDS
ACCUMULATED NEW WORK, MILLIONS OF CUBIC YARDS
25'X 100'
30'X 300'
30'X 300'(HARBOR EXTENDED)
34'X 300'
36'X 400'(WITH A.M.)
40'X 400'(WITH A.M.)
EQUATION OF THE CURVE
Y=AX²+BX
WHERE A=-0.00166
B=0.09641

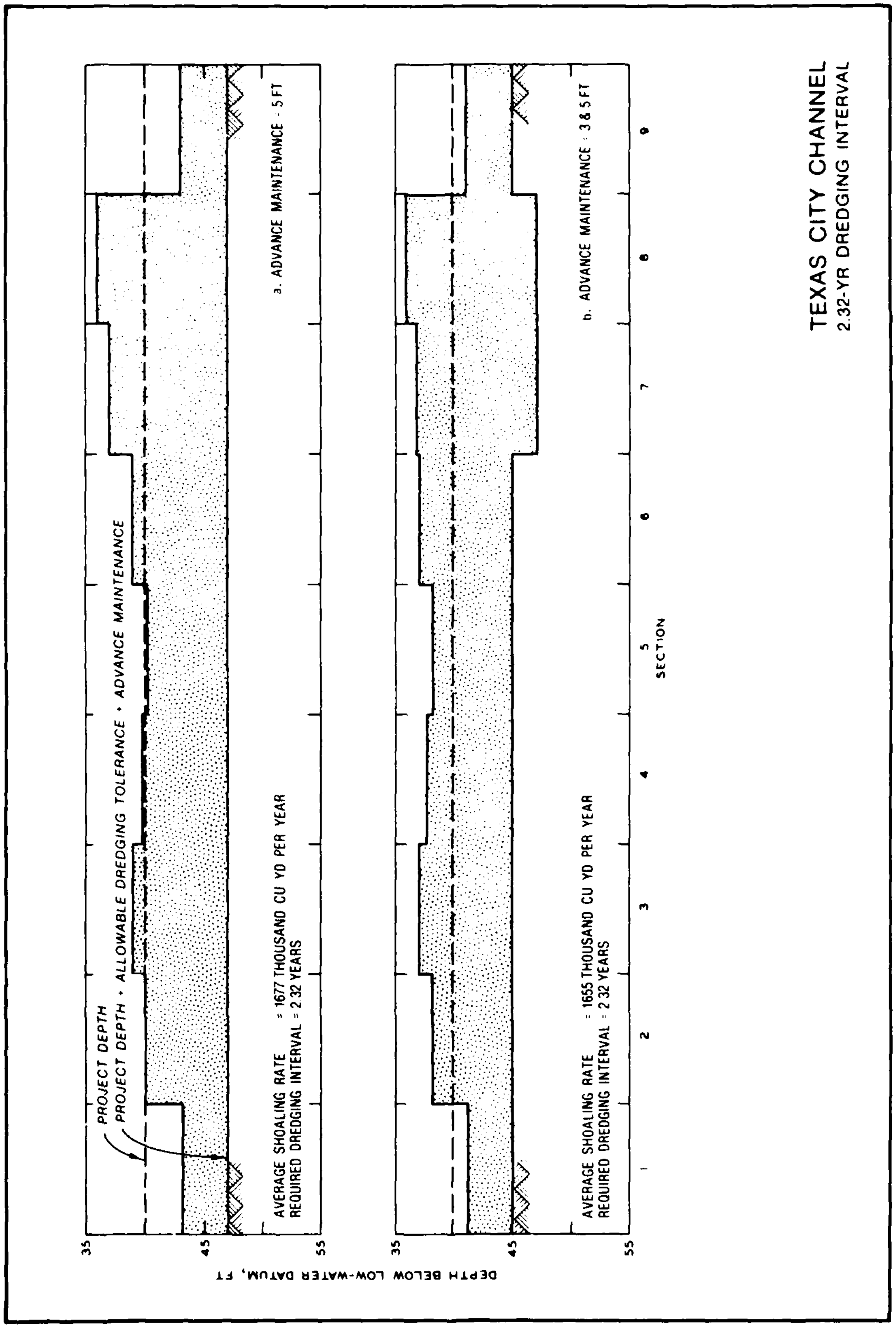
PLATE 27



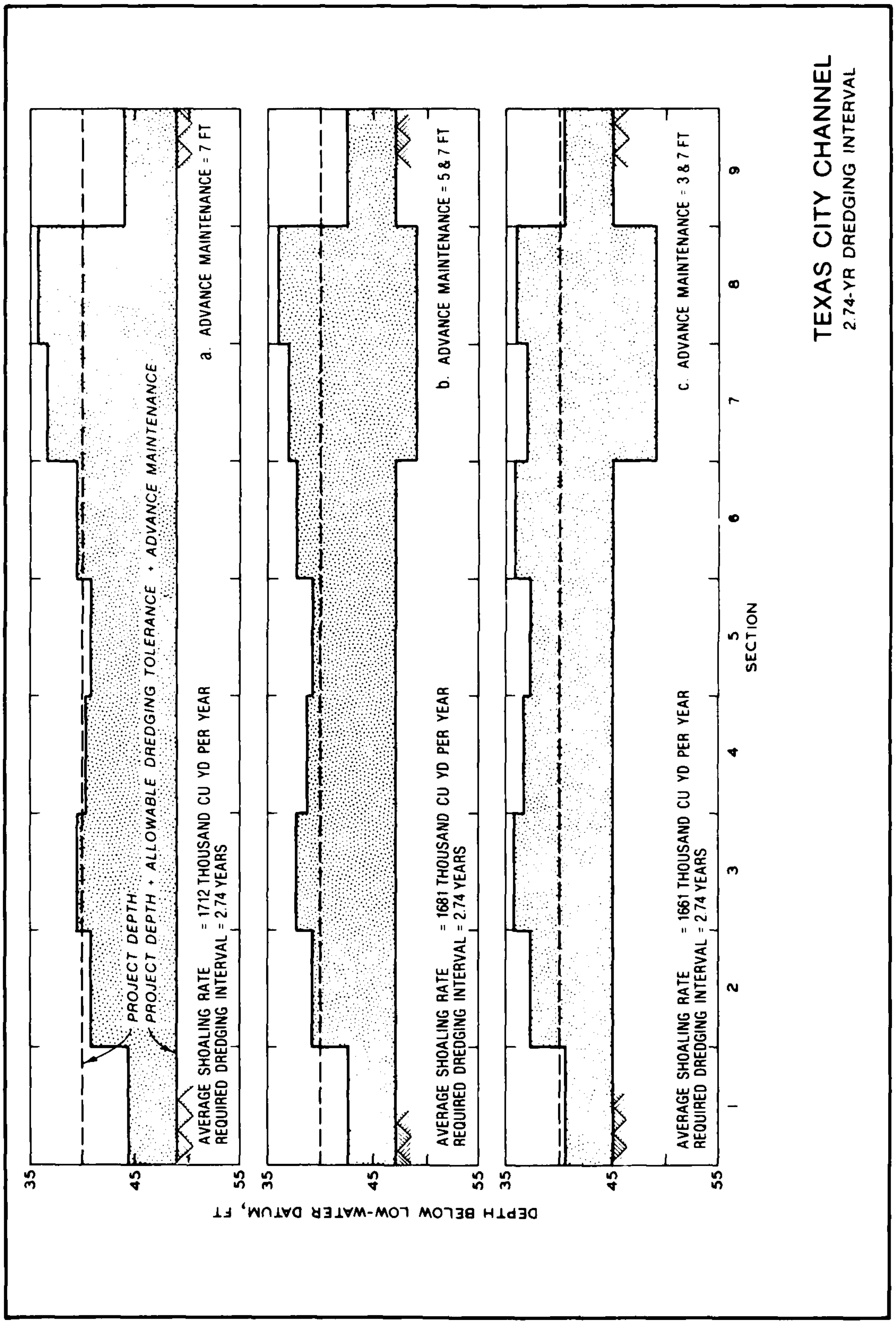

TEXAS CITY CHANNEL

SHOALING RATE-TOTAL PROJECT
ACCUMULATED NEW WORK VOLUME

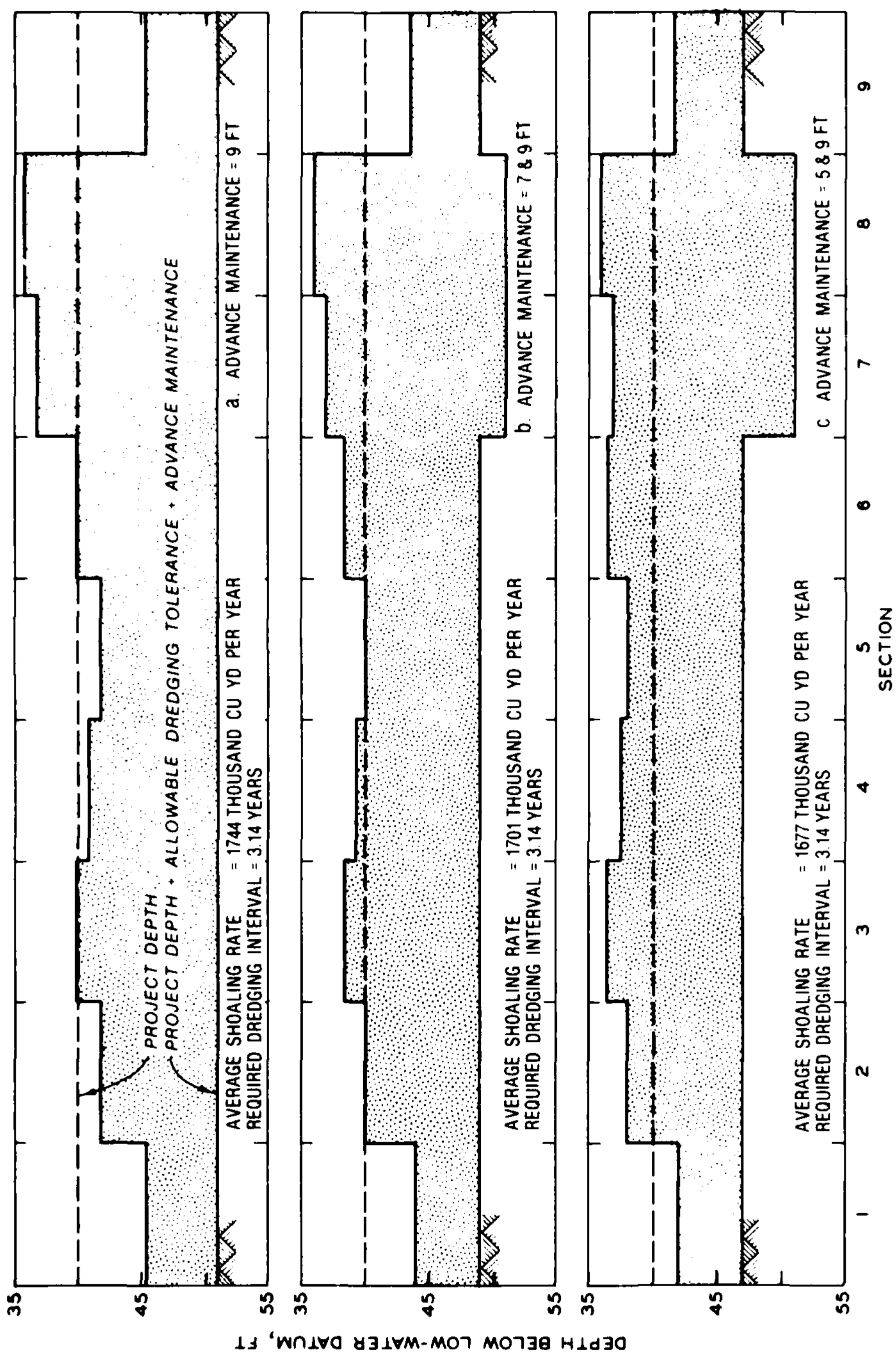
PLATE 28



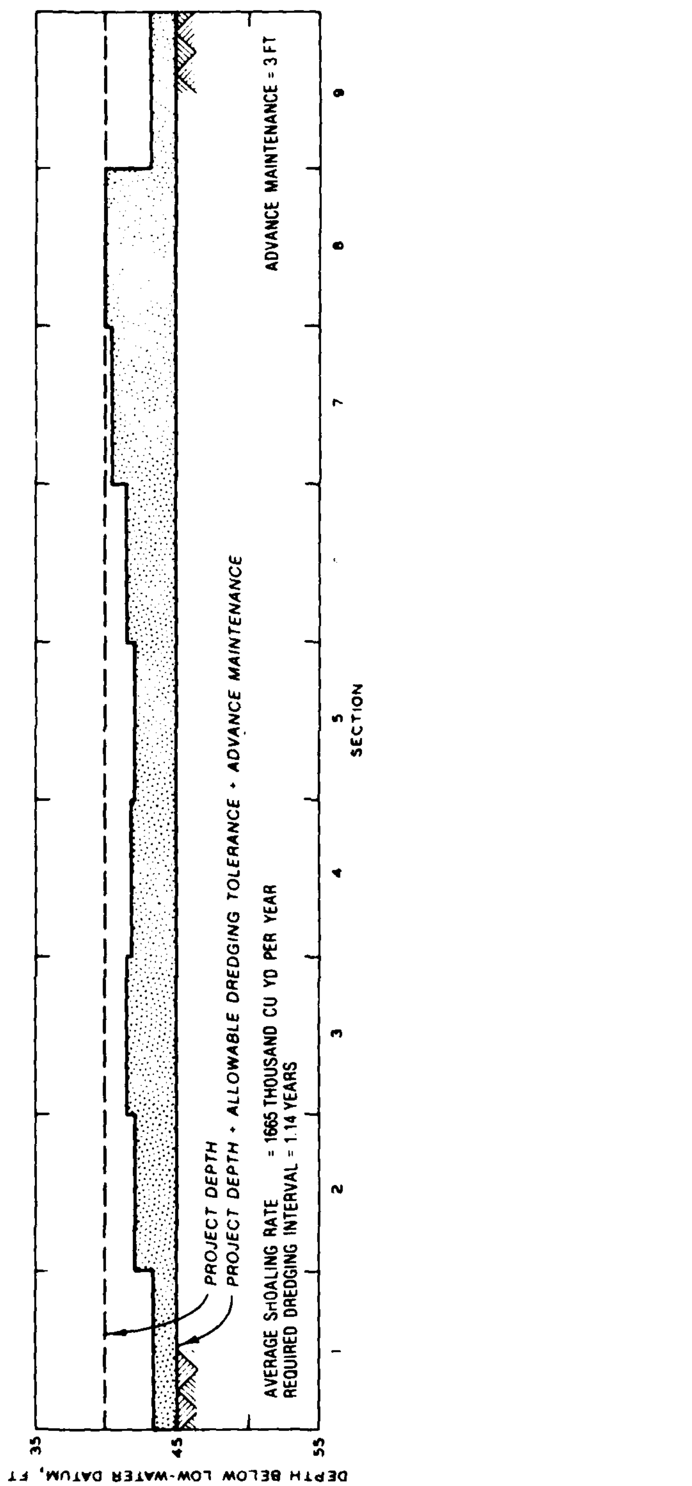
TEXAS CITY CHANNEL
2.32-YR DREDGING INTERVAL



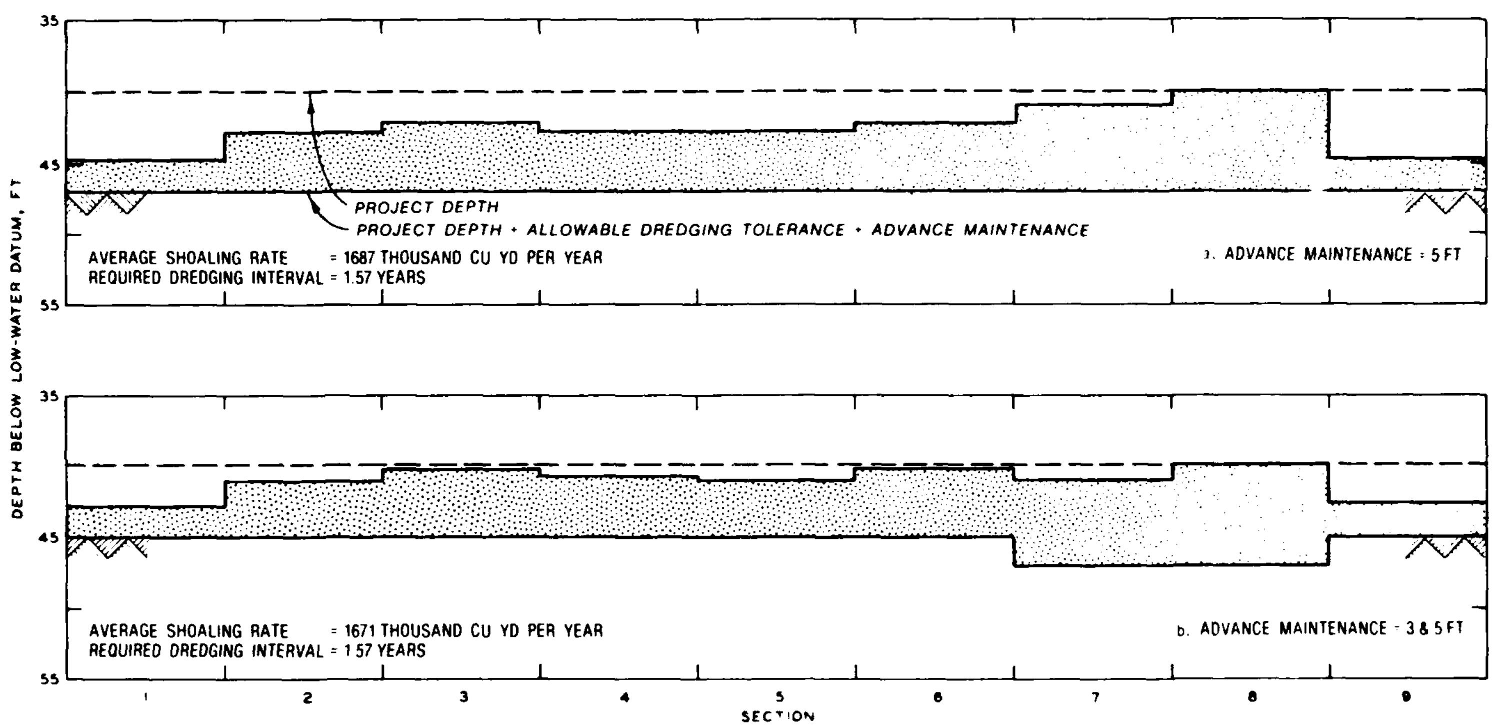
TEXAS CITY CHANNEL
2.74-YR DREDGING INTERVAL
PROJECT DEPTH
PROJECT DEPTH + ALLOWABLE DREDGING TOLERANCE + ADVANCE MAINTENANCE
AVERAGE SHOALING RATE = 1712 THOUSAND CU YD PER YEAR
REQUIRED DREDGING INTERVAL = 2.74 YEARS
a. ADVANCE MAINTENANCE = 7 FT
AVERAGE SHOALING RATE = 1681 THOUSAND CU YD PER YEAR
REQUIRED DREDGING INTERVAL = 2.74 YEARS
b. ADVANCE MAINTENANCE = 5 & 7 FT
AVERAGE SHOALING RATE = 1661 THOUSAND CU YD PER YEAR
REQUIRED DREDGING INTERVAL = 2.74 YEARS
c. ADVANCE MAINTENANCE = 3 & 7 FT
DEPTH BELOW LOW-WATER DATUM, FT
35
45
55
SECTION
1
2
3
4
5
6
7
8
9



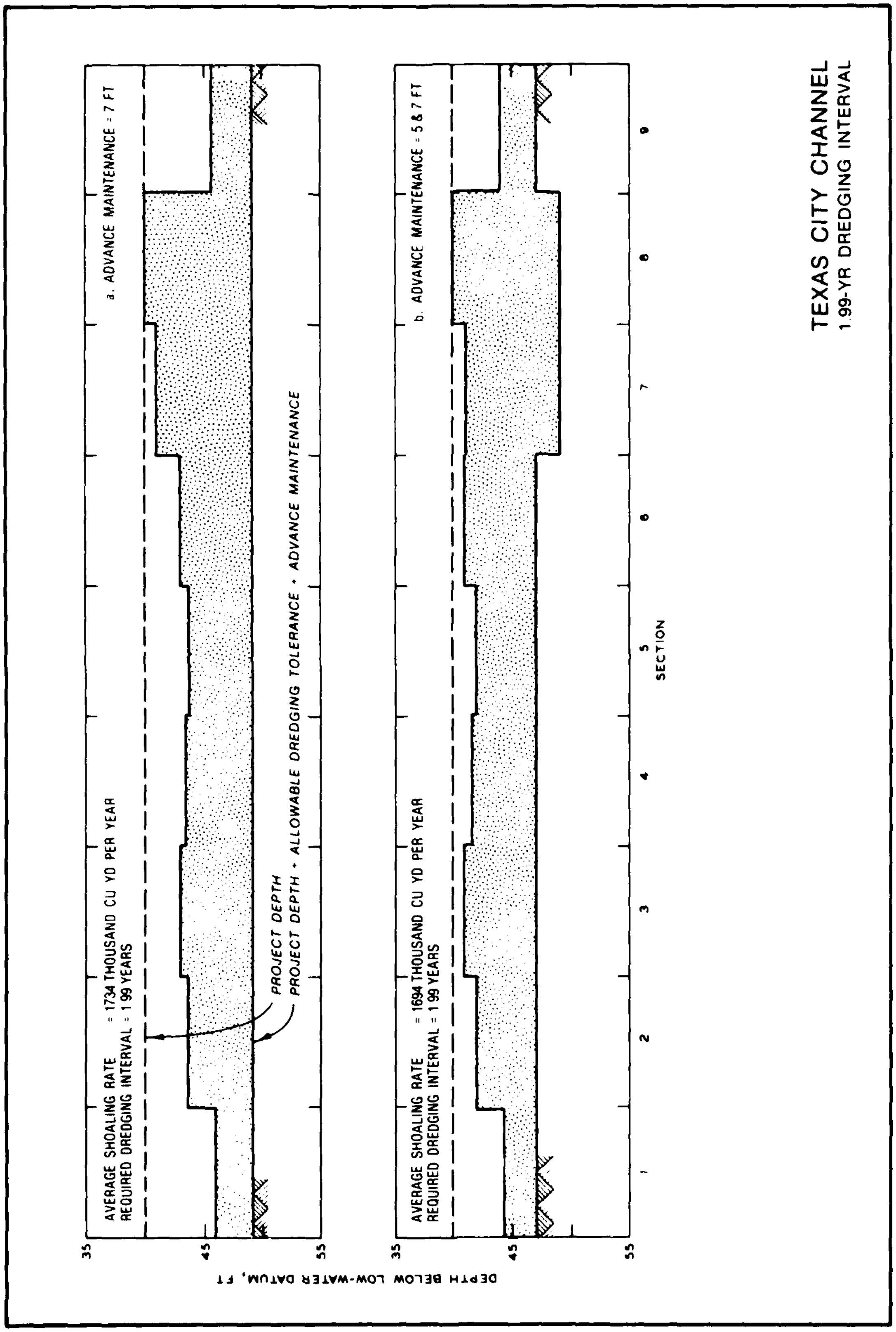

TEXAS CITY CHANNEL
3.14-YR DREDGING INTERVAL




TEXAS CITY CHANNEL
1.14-YR DREDGING INTERVAL




TEXAS CITY CHANNEL
1.57-YR DREDGING INTERVAL




TEXAS CITY CHANNEL
1.99-YR DREDGING INTERVAL

PLATE 34

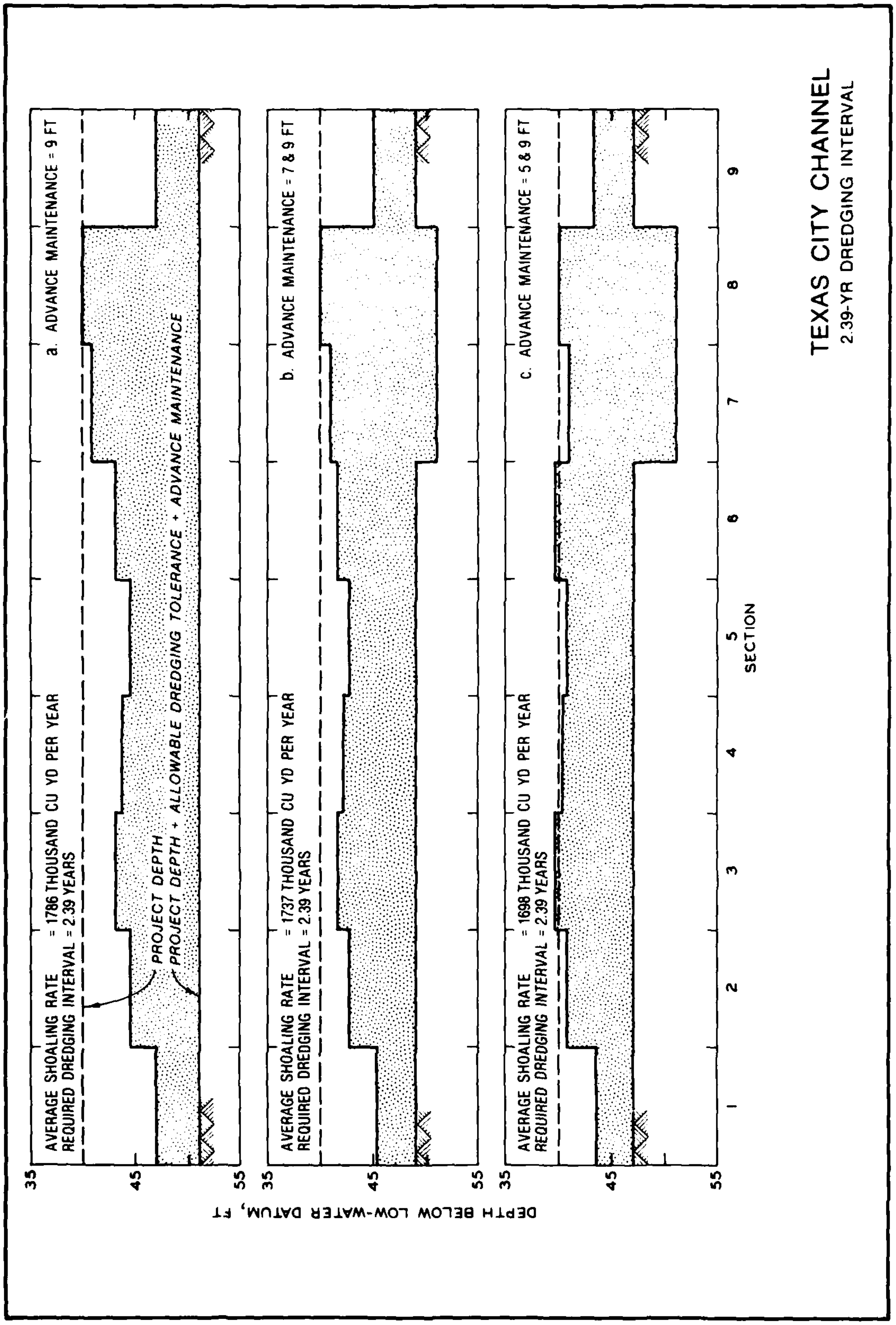
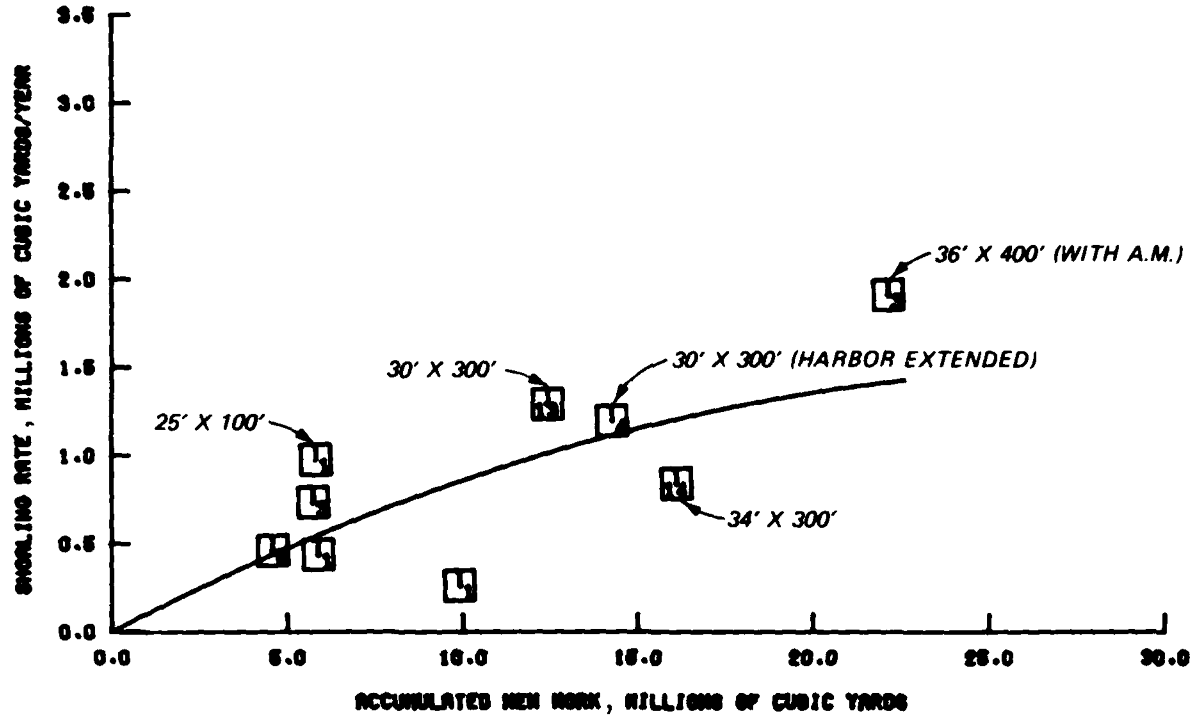

TEXAS CITY CHANNEL
2.39-YR DREDGING INTERVAL
a. ADVANCE MAINTENANCE = 9 FT
AVERAGE SHOALING RATE = 1786 THOUSAND CU YD PER YEAR
REQUIRED DREDGING INTERVAL = 2.39 YEARS
PROJECT DEPTH
PROJECT DEPTH + ALLOWABLE DREDGING TOLERANCE + ADVANCE MAINTENANCE
b. ADVANCE MAINTENANCE = 7 & 9 FT
AVERAGE SHOALING RATE = 1737 THOUSAND CU YD PER YEAR
REQUIRED DREDGING INTERVAL = 2.39 YEARS
c. ADVANCE MAINTENANCE = 5 & 9 FT
AVERAGE SHOALING RATE = 1698 THOUSAND CU YD PER YEAR
REQUIRED DREDGING INTERVAL = 2.39 YEARS
DEPTH BELOW LOW-WATER DATUM, FT
35
45
55
SECTION
1
2
3
4
5
6
7
8
9

PLATE 35




EQUATION OF THE CURVE

$Y = AX^2 + BX$

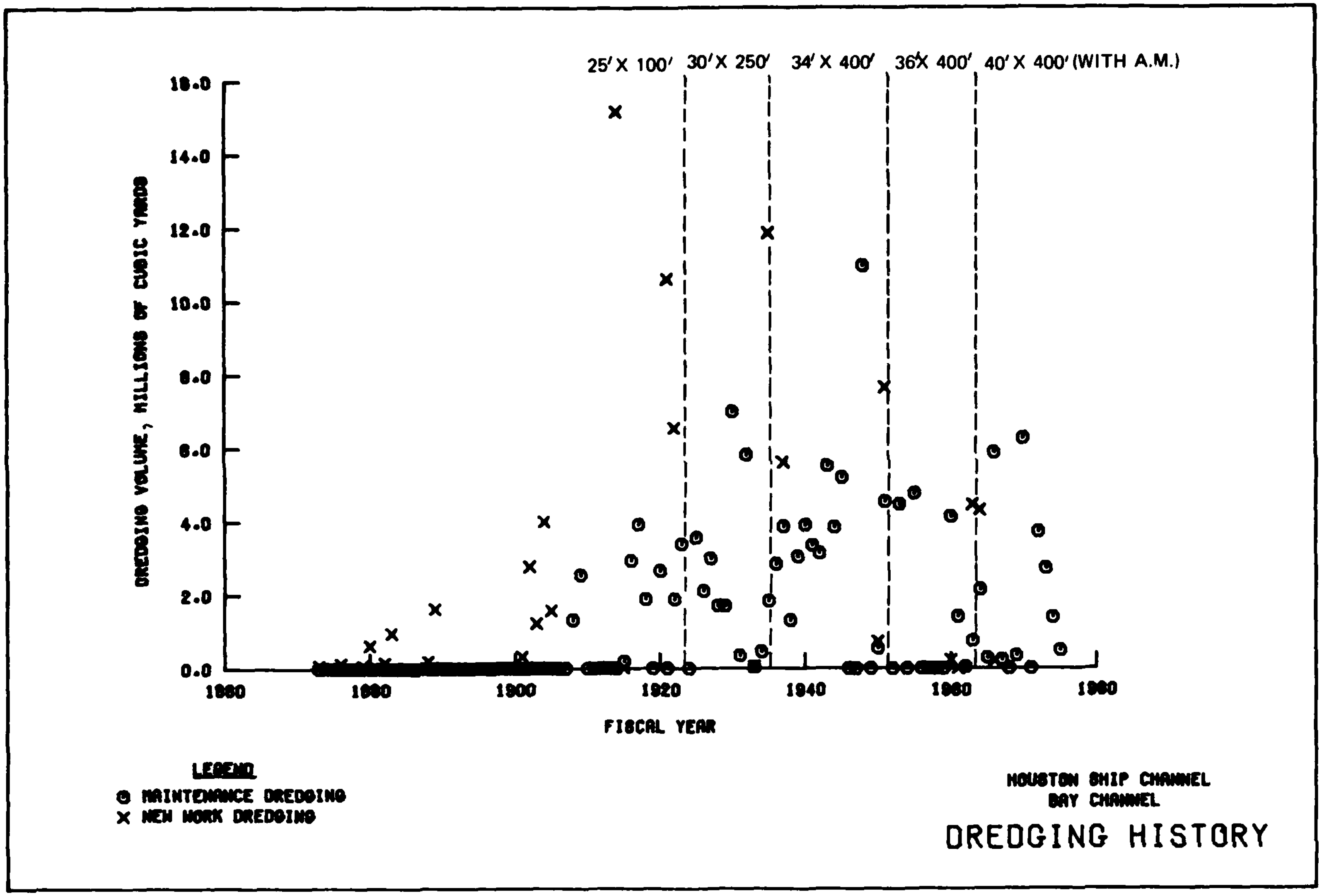
WHERE $A = -0.00192$

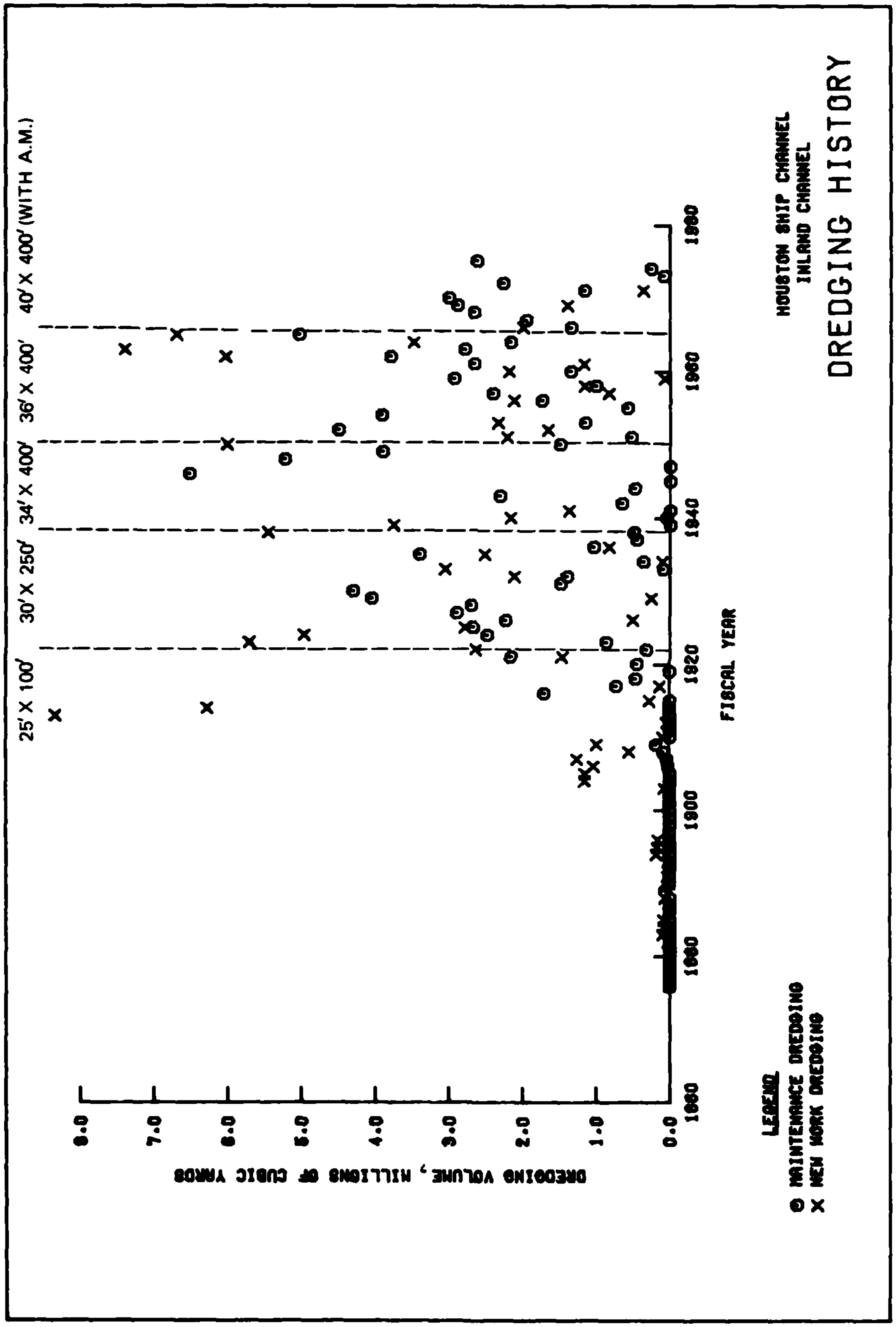
$B = 0.10410$

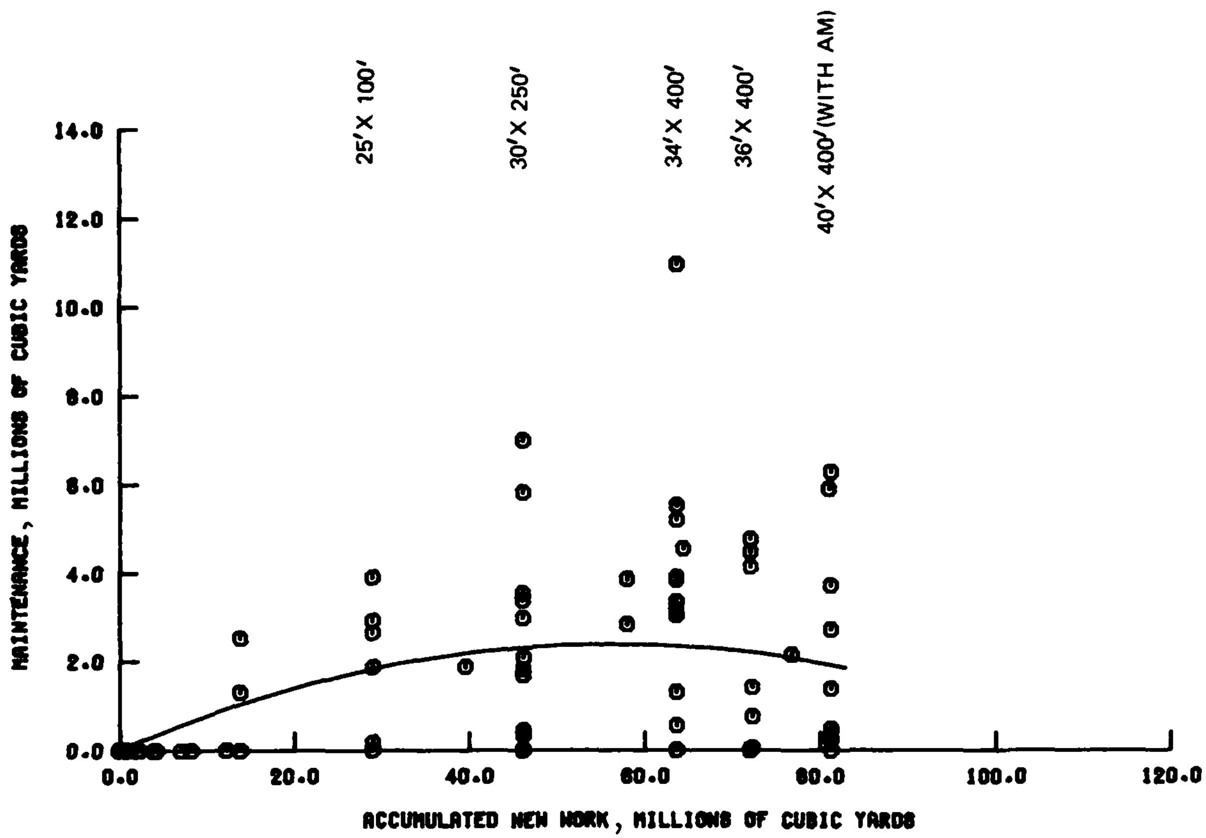
NOTE-CURVE IS WEIGHTED BY THE NUMBER OF SHOALING PERIODS. INDICATED BY THE NUMBER WITHIN THE SYMBOL

TEXAS CITY CHANNEL

SHOALING RATE-TOTAL PROJECT
ACCUMULATED NEW WORK VOLUME


25' X 100'
30' X 250'
34' X 400'
36' X 400'
40' X 400' (WITH A.M.)
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
DREDGING VOLUME, MILLIONS OF CUBIC YARDS
1860
1880
1900
1920
1940
1960
1980
FISCAL YEAR
LEGEND
⊙ MAINTENANCE DREDGING
X NEW WORK DREDGING
HOUSTON SHIP CHANNEL
BAY CHANNEL
DREDGING HISTORY


HOUSTON SHIP CHANNEL
INLAND CHANNEL
DREDGING HISTORY
25' X 100'
30' X 250'
34' X 400'
36' X 400'
40' X 400' (WITH A.M.)
DREDGING VOLUME, MILLIONS OF CUBIC YARDS
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
1860
1880
1900
1920
1940
1960
1980
FISCAL YEAR
LEGEND
⊙ MAINTENANCE DREDGING
X NEW WORK DREDGING

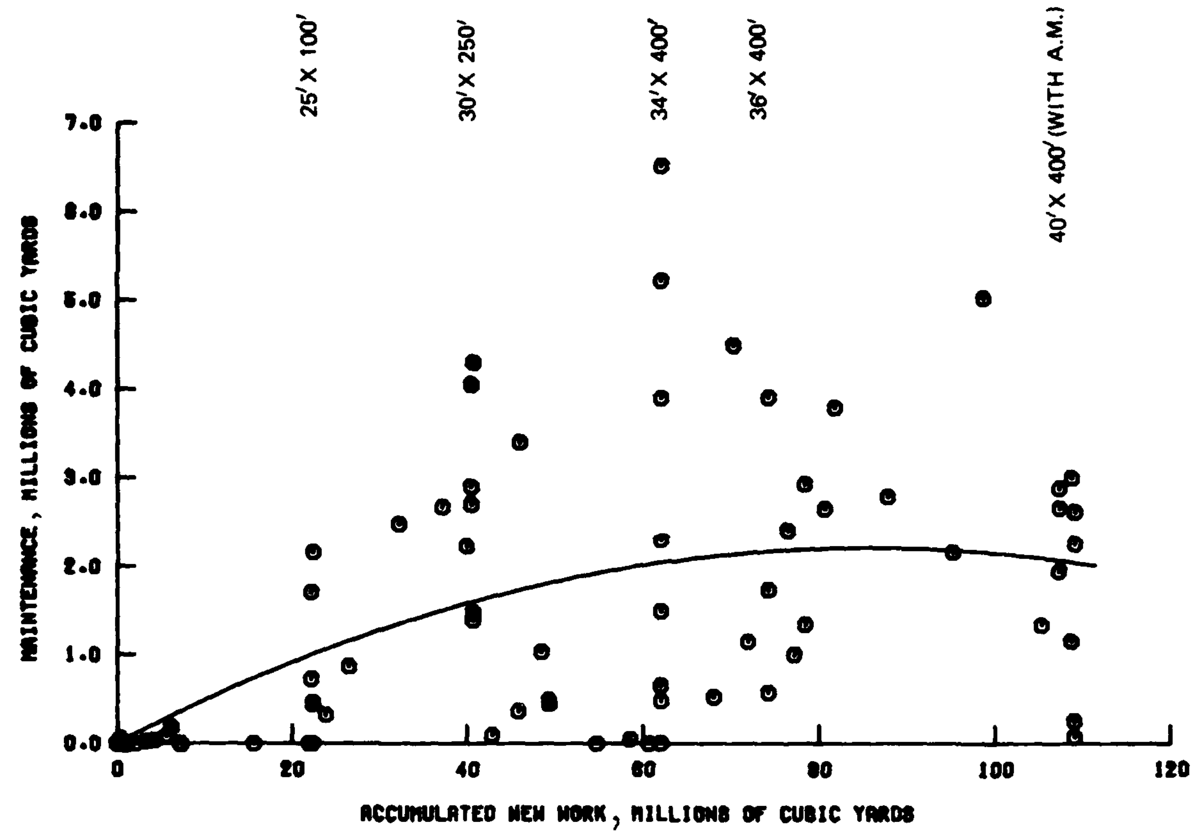



EQUATION OF THE CURVE
$Y=AX^2+BX$
WHERE $A=-0.00076$
$B=0.08639$

HOUSTON SHIP CHANNEL
BAY CHANNEL

ANNUAL MAINTENANCE-SECTION
ACCUMULATED NEW WORK VOLUME

PLATE 39

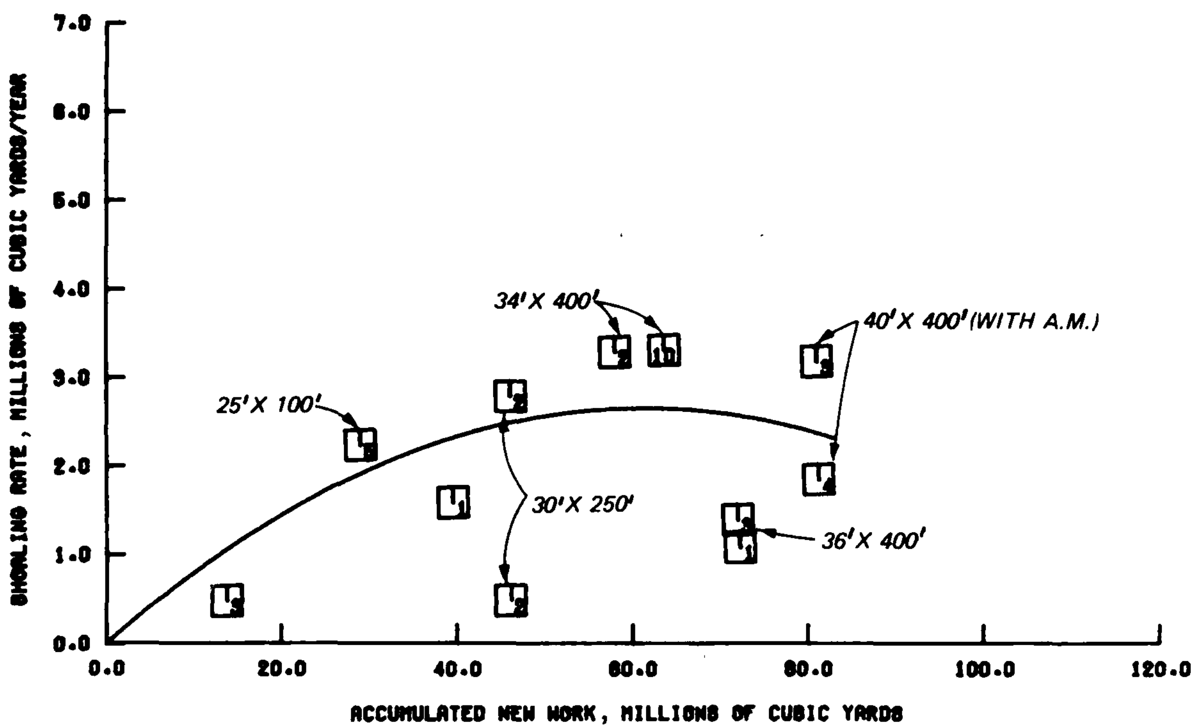



EQUATION OF THE CURVE
$Y=AX^2+BX$
WHERE $A=-0.00030$
$B=0.05168$

HOUSTON SHIP CHANNEL
INLAND CHANNEL

ANNUAL MAINTENANCE-SECTION
ACCUMULATED NEW WORK VOLUME

PLATE 40




EQUATION OF THE CURVE
$Y=AX^2+BX$
WHERE A=-0.00071
B=0.08716
NOTE-CURVE IS WEIGHTED BY THE NUMBER OF SHOALING PERIODS. INDICATED BY THE NUMBER WITHIN THE SYMBOL

HOUSTON SHIP CHANNEL
BAY CHANNEL

# SHOALING RATE-SECTION ACCUMULATED NEW WORK VOLUME

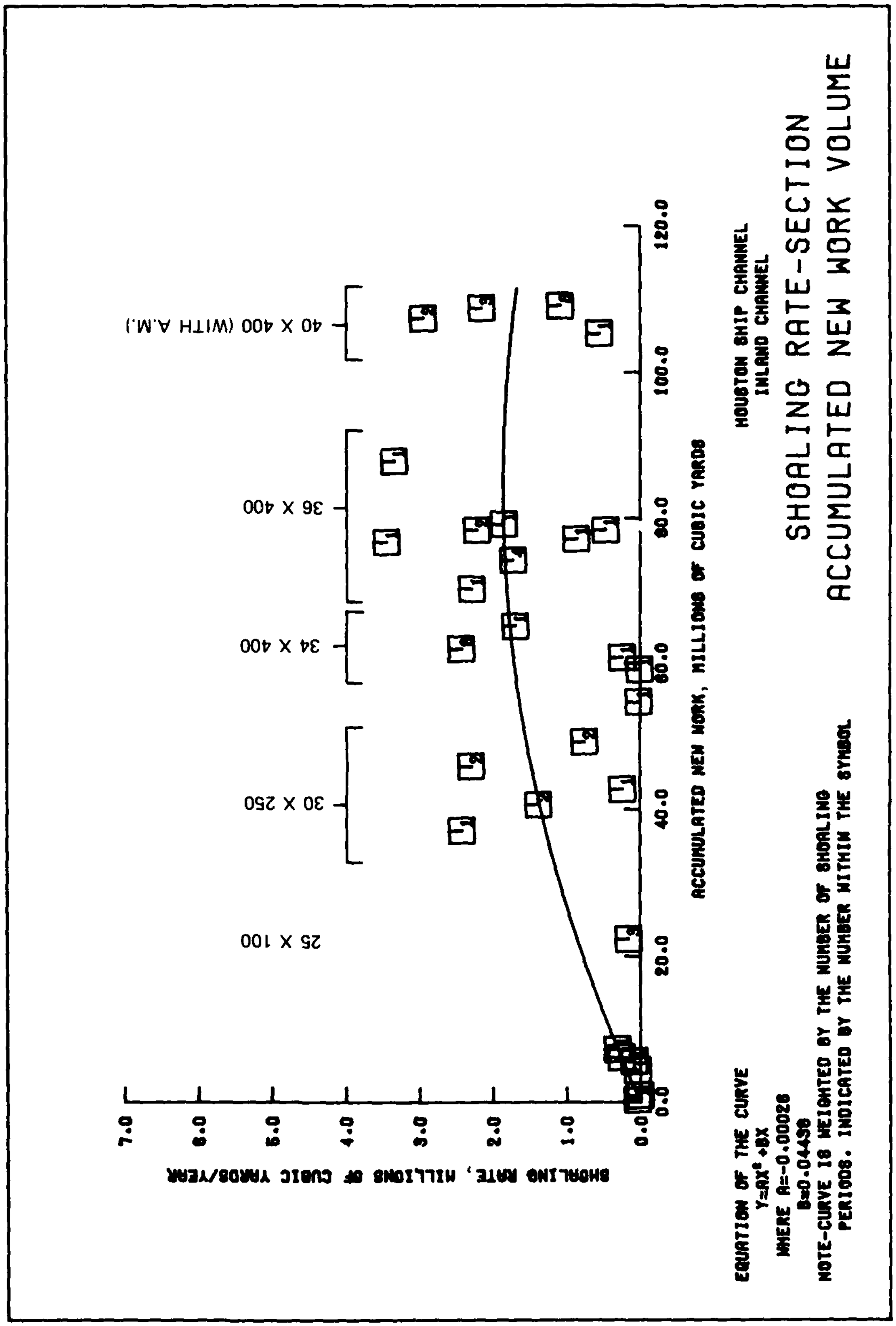

SHOALING RATE-SECTION
ACCUMULATED NEW WORK VOLUME
HOUSTON SHIP CHANNEL
INLAND CHANNEL
SHOALING RATE, MILLIONS OF CUBIC YARDS/YEAR
ACCUMULATED NEW WORK, MILLIONS OF CUBIC YARDS
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
20.0
40.0
60.0
80.0
100.0
120.0
25 X 100
30 X 250
34 X 400
36 X 400
40 X 400 (WITH A.M.)
EQUATION OF THE CURVE
Y=AX²+BX
WHERE A=-0.00026
B=0.04436
NOTE-CURVE IS WEIGHTED BY THE NUMBER OF SHOALING
PERIODS. INDICATED BY THE NUMBER WITHIN THE SYMBOL

PLATE 42

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.


Trawle, Michael J.
Effects of depth on dredging frequency : Report 2 : methods of estuarine shoaling analysis / by Michael J. Trawle (Hydraulics Laboratory, U.S. Army Engineer Waterways Station). -- Vicksburg, Miss. : The Station ; Springfield, Va. : available from NTIS, [1981].
65 [25] p., 42 leaves of plates : ill. ; 27 cm. -- (Technical report / U.S. Army Engineer Waterways Experiment Station ; H-74-5, Report 2)
Cover title.
"July 1981."
"Prepared for Office, Chief of Engineers, U.S. Army."

1. Channels (Hydraulic engineering). 2. Dredging. 3. Harbors--Maintenance and repair. I. United States. Army. Corps of Engineers. Office of the Chief of Engineers. II. U.S. Army Engineer Waterways Experiment Station. Hydraulics Laboratory. III. Title IV. Series: Technical report (U.S. Army Engineer Waterways Experiment Station) ; H-78-5, Report 2.
TA7.W34 no.H-78-5 Report 2

DATE

ILMED

-8